Retro-innovating

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São Paulo/ Brazil - A Case Study

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Retro-innovating
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A flower sprang up in the street!
Far away, streetcars, buses, a steel river of traffic passed by.
A lack-lustre flower
Eludes the police, tears the asphalt.
They are completely silent, business is paralysed,
I swear a flower sprang up.

Its colour is imperceptible.
Its petals do not open.
Its name does not appear in books.
It is ugly. But it really is a flower.

"The Flower and Nausea" 1945
Carlos Drummond de Andrade (1902 - 1987)

Uma flor nasceu na rua!
Passem de longe, bondes, ônibus, rio de aço do tráfego.
Uma flor ainda desbotada
ilude a polícia, rompe o asfalto.
Façam completo silêncio, paralisem os negócios,
garanto que uma flor nasceu.

Sua cor não se percebe.
Suas pétalas não se abrem.
Seu nome não está nos livros.
É feia. Mas é realmente uma flor.

"A Flor e a nausea" 1945
Carlos Drummond de Andrade (1902 - 1987)

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LIST OF ABREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AOI	Area of Interest
BRT	Bus Rapid Transit
BVOC	Biogenic Volatile Organic Compounds
CBD	Central Business District
CFD	Computer Fluid Dynamics
DBH	Diameter at Breast Height
DPI	Dots Per Inch
GDP	Gross Domestic Product
GIS	Geographical Information System
GIw	Weighted Green Index
GPR	Green Plot Ratio
IBGE	Instituto Brasileiro de Geografia e Estatística
IDH	Índice de Desenvolvimento Humano
HVAC	Heating, Ventilating and Air Conditioning
QoL	Quality of Life
LAI	Leaf Area Index
LAD	Leaf Area Density
MRT	Mean Radiant Temperatures
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental organization
SVF	Sky View Factor
PAR	Photosynthetically Absorbed Radiation
PET	Physiologically Equivalent Temperature
RAMS	Regional Atmospheric Modelling System
SVMA	Secretaria do Verde e do Meio Ambiente
SEADE	Fundação Sistema Estadual de Análise de Dados
TEP	Temperature of Equivalent Perceptive
UHI	Urban Heat Island
PLEA	Passive and Low Energy Architecture
PPM	Parts Per Million
WHO	World Health Organization
WMO	World Meteorological Organization
WWR	Wall-Window-Ratio
VDI	Verein Deutscher Ingenieure

ZUSAMMENFASSUNG

Die vorliegende Studie analysiert Umweltdienstleistungen von städtischer Vegetation innerhalb der Stadtgrenzen einer Megacity durch maßstabsübergreifende Modellierung und versucht ihren Nutzen näherungsweise zu quantifizieren. Aus verschiedenen Blickwinkeln werden die Vorteile (sowie die Herausforderungen) von in Städte eingebetteter Natur für die Bevölkerung aufgezeigt. Aus geographischer Sicht wird, hier am Fallbeispiel der Stadt São Paulo/ Brasilien, das Profil der Megastädte in den niedrigen (tropischen) Breiten betrachtet.

Im allgemeinen wird die städtische Vegetation dort von Bevölkerung, Regierungen und ökonomischen Strukturen vernachlässigt. Sie ist zwar spärlich vorhanden, wird aber kaum bewusst wahrgenommen. Während der kurzen Geschichte rasanter Verstädterung, die von massiver Umweltzerstörung begleitet ist, wird Stadtgrün im Disput um den Raum in Städten wie São Paulo zum wahren Luxus.

Nicht als Rückentwicklung, sondern als Fortschritt, wird gezeigt, daß ein Ideal durch die Verflechtung zwischen Natur und Stadt dargestellt würde. Die näherungsweise Quantifizierung der Variationen zwischen aktuellem Szenario und begrünten Szenarien zeigt die Notwendigkeit das städtische Biom als ein vom Menschen dominiertes Ökosystem neu zu überdenken.

Die Nutzen von städtischer Vegetation sind facettenreich. Diese Arbeit detailliert Vegetation als Katalysator des klimatischen und ökologischen Gleichgewichtes. Des weiteren behandlt sie aktuelle Themen wie Klimawandel, Energieeffizienz und thermische Behaglichkeit, sowie die Reinigung der natürlichen Ressourcen Boden, Wasser und Luft. Insbesondere da derzeit keine effizienten technischen Lösungen existieren, um die Umweltleistungen der Vegetation zu ersetzten.

Diese Nutzen tragen zur Lebensqualität und in kontrastreichen Megastädten insbesondere zu sozio-ökologischer Gerechtigkeit bei. Die Vegetation hat in Städten zwei wichtige Dimensionen. Die funktionale Seite bringt konkrete, meßbare Umweltnutzen. Aus symbolischer Sicht repräsentiert Vegetation Natur in Städten, sowie ursprüngliche Naturverbundenheit des Menschen.

Zusammenfassend verteidigt die Studie die Wichtigkeit und Wertschätzung von Natur und die vereinigten Anstrengung für wirklich grüne Städte, u.a. weil diese Arbeit zeigt, dass finanzielle Investitionen in städtische Vegetation sich direkt auf die Kosten für das Gesundheitssystem und die Infrastruktur auswirken.

Die Stadtregierung São Paulo investierte 2008 umgerechnet 122 Millionen Euro (einhundertzweiundzwanzig Millionen Euro) in Stadtgrün (und Umwelt), dass jährlich mindestens 665 Millionen Euro (Sechshunderfünfundsechzig Millionen Euro) einspart. D.h. mit anderen Worten, dass jeder Euro 1 der in Pflanzung und Pflege von Stadtgrün investiert wird, der Gesellschaft, und damit letzendlich den Einwohnern São Paulos, Ausgaben von mindestens 5 Euro für Gesundheit, den Bau von Regenwasserrückhaltebecken, Energie etc. einspart.

ABSTRACT

The present study analysis the environmental benefits of urban vegetation within the municipal boundary of a megacity through multi scale integrated modelling to estimate its benefits approximately. The advantages (and challenges) that Nature, inserted into cities, offers to the population are observed from different viewpoints. As geographical reference the profile of megacities located in low (tropical) latitudes was observed, in a case study on the city of São Paulo/ Brazil.

Commonly, urban vegetation is overlooked by local people, governments and economical structures. Although sparse vegetation exists, it is hardly recognized. Along the brief history of rapid urbanization which is accompanied by massive environmental degradation, urban green becomes, in the dispute for space, a true luxury in cities like São Paulo.

Not as retrogression but as advance, it demonstrates that the integration between nature and city would be desirable. The approximated quantification of the variations which occur between actual scenario and greened scenarios shows the need to rethink the urban biome as a man-dominated ecosystem.

The benefits of the urban vegetation are diverse. This work details plants as agents of climatic and ecosystem balance and performance. It also approaches current issues like climate change, energy efficiency and thermal comfort, as well as the purification of natural resources, through the treatment of water, soil and air. Especially because at present no efficient technical solutions exist, that could substitute the environmental services of the vegetation.

These benefits contribute to quality of life and increase socio-environmental equity especially important in high-contrast megacities. The vegetation assumes two important roles in cities. The functional dimension brings concrete and measurable benefits to the environment. From a symbolic vision, vegetation represents Nature in cities, approximating humans to their origins.

Conclusively the study defends the importance of the valorization of Nature and of the united efforts for literally green cities because it proves that financial investment in urban vegetation has direct effects on the costs destined to the areas of health and infrastructure.

The City of São Paulo, invested in 2008 about US$ 180 million (one hundred and eighty million dollars) in urban green (and environment) which tends to save US$ 980 million (nine hundred and eighty million dollars) of expenses annually. In other words, for each US$ 1 invested in planting and maintenance of urban green, the society saves at least US$ 5 of expenses in health, construction of French drains, energy etc.

RESUMO

O presente estudo faz uma profunda análise dos benefícios ambientais da vegetação urbana dentro dos limites municipais de uma megacidade através de modelagem integrada de múltiplas escalas visando estimar os benefícios aproximadamente. Um conjunto de fatores expõe as vantagens (e os desafios) que a Natureza, inserida dentro de cidades, traz à população. Como referência geográfica, foram consideradas as características de megacidades localizadas em latitudes baixas (tropicais), como é o caso da cidade de São Paulo.

Comumente, a vegetação urbana é negligenciada por pessoas, governos e estruturas econômicas. Ela está lá, mas quase ninguém vê. Ao longo da História, o processo de urbanização veio acompanhado da degradação ambiental, e, na disputa pelo espaço, o verde se tornou um verdadeiro luxo em cidades como São Paulo.

Sem a pretensão de um retrocesso no desenvolvimento, fica provado que ideal seria a integração entre natureza e cidade. Quantificar as mudanças ocorridas com e sem as plantas urbanas, traz à tona a necessidade de repensar o bioma e o ecossistema na civilização dominada pelo homem.

Os benefícios da vegetação urbana são diversos. Esse trabalho detalha o seu desempenho como agente de equilíbrio climático e do ecossistema. Aborda também questões atuais como mudanças climáticas, eficiência energética e conforto térmico. E ainda, a purificação dos recursos naturais, através do tratamento de água, solo e ar. Principalmente, porque ainda não existe nenhuma solução técnica tão eficiente que possa substituir os serviços ambientais da vegetação.

Todos esses benefícios são claramente vistos como fatores de qualidade de vida, comprovando que a vegetação urbana contribui para a igualdade socioambiental. A vegetação assume dois importantes papéis nas cidades. O lado funcional onde traz benefícios concretos e mensuráveis ao meio ambiente. E sob uma visão simbólica, representa a natureza no meio urbano, aproximando o homem de suas origens.

Conclusivamente, o estudo defende a importância da valorização da natureza e do esforço conjunto por cidades literalmente verdes, pois comprova que o investimento financeiro em vegetação urbana impacta diretamente nos custos destinados às áreas de saúde e infraestrutura.

Tomando como exemplo a cidade de São Paulo, a Prefeitura Municipal investiu em 2008 em verde (e meio ambiente) cerca de R$ 330 milhões (trezentos e trinta milhões de reais), tendo uma economia nos gastos estimada em R$ 1,8 bilhão (um bilhão e oitocentos milhões de reais) por ano. Ou seja, a cada R$ 1 investido em plantio e manutenção de áreas verdes, a sociedade deixa de gastar no mínimo R$ 5 em despesas com saúde, construção de "piscinões", canalização de córregos, energia, entre outros.

1. INTRODUCTION

“A systematic change is on the horizon, whereby the boundary between the natural and the manufactured no longer exists” (Michael Weinstock, 2006)

Fig. 1.1: *Map of the ecumenópole, resulting of the composition of satellite images obtained at night between 1994 and 1995 (Menegat, 2008)*

Nature surrounded by Civilization

In the urban age megacities sprawl into the surrounding pristine tropical forests all over the planet, literally eating up natural resources causing environmental damages yet unmeasured. A global conurbation of the megacities in a world wide urbanization pattern was already anticipated by Konstantinos Apostolos Doxiadis[1] (1913-1975) in the *Ecumenopolis* (1976).

The Greek city planner described how progressive urbanization would lead inevitably to an urbanized planet and expected – much in contrast to the *Boarders of Growth* Report (*Club of Rome* and Meadows, 1972) - an environmental equilibrium.

The manual for the elaboration of *Geocity Reports* of the *United Nations Environment Program* (UNEP) is based on the circular concept of *Pressure -> Space -> Impact -> Response* and states that “urbanization is a powerful pressure factor on the environment”. The environment supplies the growing demands of the population and the economic activities of the urban centers and receives in return the waste of the use of its natural resources (PNUMA/ SVMA/ IPT, 2004).

São Paulo was one of the first cities of the 20th century to swell to megacity status. It was chosen for this case study because it is considered an almost iconic (relatively old) example of a *megacity* with all its cultural benefits and environmental problems (see Brazilian geographer Milton Santos) and with a widely very low fraction of vegetation cover. The tendencies of the spatial pressures, impacts and responses of the urban culture on the environment analyzed here can hopefully also be transferred to other, newer megacities under similar conditions.

In fact since São, Paulo is located on the *Tropic of Capricorn*, thus the margin of the tropical belt, it can be expected that the benefits of urban vegetation (as a representation of urban *Nature*) are even higher in the higher latitudes, according to the *latitude theory* (see page 124).

The rapid process of urbanization in São Paulo led to widely to disregard and “expulsion” of natural elements (vegetation, rivers, creeks, open soils, etc.) within the metropolitan

[1] Interestingly Konstantinos Doxiadis also developed an urban development plan for Rio de Janeiro in 1965 (see Arch+ No. 190)

area, while climatic phenomena react with unforeseen intensity to the land-use change over an almost completely urbanized area of an mean diameter of 60 kilometers.

> "Cities, often thought of as the inverse of nature, are now recognized as the most environmentally friendly way to house the world's increasing population. In theory people who live in [dense] cities leave a [relatively] smaller footprint on the environment per capita than people living in other [less dense] types of communities, [such as Garden Cities/ or suburbs] but usually have as well less access to green areas. It's obvious that high-density development can help preserve the environment outside urban areas but what does it do to the urban environment? As [world-wide] more [and more] people move into cities, [consequently] more and more [climate regulating] tree cover is being lost" (American Forests, 2004).

Urban *land-use* (or *footprint*) of cities, together with *population density* (short ways) and *urban quality of life* belong to the most discussed and urgent issues of *sustainable cities*, especially when discussing the transformation of megacities located mostly in the lower latitudes (close to and within the tropical belt).

> "In [many tropical, emerging and] developing countries, people often migrate to cities because of crop failures, natural disasters, or armed conflicts, not because cities have robust economies capable of supporting more people. In the coming decades, many new city dwellers will be desperately poor. With little access to air conditioning, refrigeration, or medical care, the world's urban poor will be particularly vulnerable to heat wave health hazards." (Interview with Stuart Gaffin 2006[2])

Vegetation in cities has additionally, due to the climate, more important impacts on *quality of life*, especially on the *thermal*

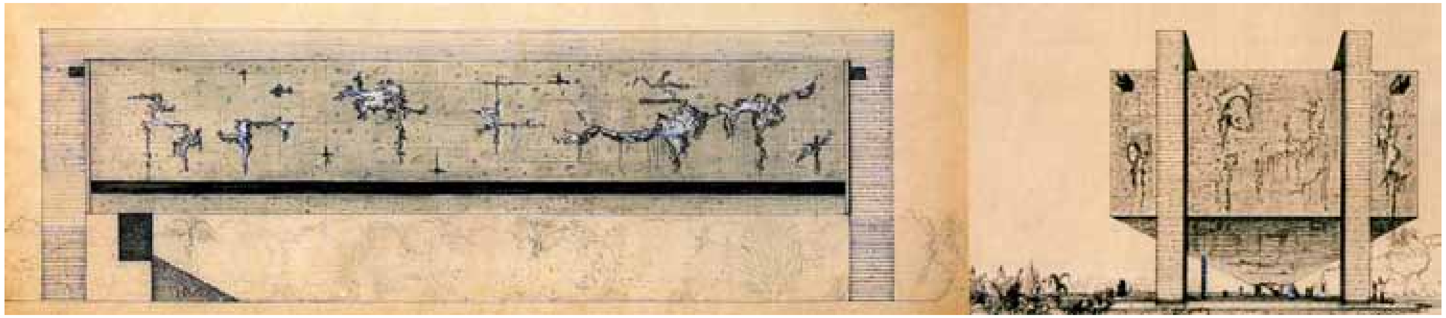


Figure 1.2: *Preliminary design sketches for the vegetated fascades of São Paulo's Museum of modern Art by Lina Bo Bardi (1965)*[3]

quality of the sprawling urban structures. Although vegetation can not solve all of their problems it plays a paradoxical key role for the new paradigm of urban sustainability.

Necessity of the present study

Urban vegetation is one of the most obvious elements to increase environmental quality and to partially reverse the negative environmental impacts of urbanisation, but in the urbanistic discourse (after the *Garden City* and Le Corbusier's *Vertical Green City,* see chapter 3.1.2) of the twentieth century, it can be observed that urban vegetation has often been overlooked, probably because it does not represent urbanity in its traditional sense.

Interestingly some modern, Brazilian architects and landscape planners sought - probably more than in any other regional, modern architecture – for a dialog between their constructions and the surrounding tropical *Nature* in some rare constructed examples (see e.g. Roberto Burle Marx's Gardens in collaboration with Oscar Niemeyer, Lúcio Costa in Brasília and Lina BoBardi's preliminary designs for the Museum of Modern Art in São Paulo).

However, it seems that with the end of the industrial age the strongly modified relation between humans and their environment (or Nature) needs to be revised and discussed.

> "We need most of all to renew that love and empathy for nature that we lost when we began our love affair with city life. Socrates was probably not the first to say that nothing happens outside the city walls, but he would have been familiar with the natural world outside. Even in Shakespeare's time cities were small enough for him to walk to 'a bank whereon the wild thyme blows, where oxlips and nodding violet grows'.
>
> The early environmentalists who knew and truly appreciated nature – Wordsworth, Ruskin, Rousseau, Humboldt, Thoreau and so many others – lived for much of their lives in small compact cities. Now the city is so huge that few ever experience the countryside, it is so distant. I wonder how many of you know what an oxlip looks like or have seen one" (James Lovelock in Revenge of Gaia, 2006 p. 10,11)

> "We need to walk, just as birds need to fly. We need to be around other people. We need beauty. We need contact with nature. And most of all, we need not to be excluded. We need to feel some sort of equality." (Enrique Peñalosa, former mayor of Bogotá/ Columbia)

Analyzing urban environmental parameters and elements Ali-Toudert (2005) reports e.g. that studies on the effects of urban vegetation on thermal outdoor comfort are very few, in particular those specifically addressed to urban streets (e.g. Shashua-Bar and Hoffmann, 2000).

The complex phenomenon of the urban climate is in contrast well researched (Ali-Toudert, 2005) and the use of green as a strategy to mitigate the urban heat island (UHI) and improve the microclimate has been widely emphasized (e.g. Escourrou 1991, McPherson et al. 1994a, Akbari et al. 1995, Avissar 1996, Taha et al. 1997).

The scientific revision of the exaggerated

[2] Online http://earthobservatory.nasa.gov/Features/GreenRoof/printall.php <access on 25th of June 2009>
[3] Not executed, only the backside of the museum includes vegetation

urban growth during the twentieth century seeks (especially due to its continuity) for quantitative benchmarks to define strategies. The need for quantitative studies (besides the many qualitative ones) was put forward by various authors, e.g. Givoni (1997) and Katzschner (2007). Ong (2003) resumes that the "full benefits of plants and the role they play in the *urban ecology* remain to be mapped out while the general significance of plants appears to be uncontested".

Key questions approached in this work are:

- What is *Nature* and what is Growth? How do, can we, should we modify *Nature*? What is the nature of *Nature*?
- What is (and will be) the composed impact of urban heat islands and global warming, which will create hot conditions for more than half of the world's population housed in tropical megacities in the future?
- How does (and will) urbanization and climate change affect the urban water and energy balances and consumption, consequently *urban quality of life*?
- In how far will especially megacities be exposed or adapted to climate, and in how far the urban climate adaptation process is discussed, desired and possible today and at local and city-wide scale?
- Do people accustomed to natural environments (in Brazil for example those migrated from the rural Northeast) miss the amenities of vegetation in the megacities?
- Is urban vegetation rather a *basic need* or *luxury* in socio-environmentally contrasty megacities of urbanized emerging countries localized in low (tropical) latitudes (especially when other basic needs become unsatisfied)?
- In how far are the non-constructed vital urban elements of urban vegetation technically necessary or rather replaceable? Or are they - well integrated with engineered solutions - even the only feasible solution at this point to increase urban efficiency and productivity in the long run?
- How to measure, simulate and verify sustainable, climate-sensitive urban development, quality of life, environmental comfort etc.?
- How to define comprehensive environmental indicators to measure *quantum change* of urban development under local and global circumstances, considering climate change?
- Is it possible (or useful) to monetize simulated environmental benefits to convince decision makers?

Without pretension on correctness of the results this work principally explores links between environment and economy and methods to estimate the impacts of urban vegetation in São Paulo. It also discusses social aspects because these themes cannot be observed apart, when discussing urban sustainability.

The work addresses first of all citizens, because they are affected. Among them decision-makers and stakeholders, not at least it includes hopefully some useful information for urban planners and designers, such as spatial planners, architects, landscape designers, biologists etc. It was intended to use simple English language limiting technical language to a necessary amount in order to make it widely understandable. A translation to Portuguese is planned for the near future.

Objective

The aim of this study is to give an overview of the state of *urban ecology* and the role of metropolitan vegetation and its properties (parameters) in a tropical megacity. To better understand the reciprocal relation between the city and its vegetation, the links between urban ecosystems, the thermal complex (laws of thermodynamics), the hydrological complex and the urban morphology[4] needs multidisciplinary approaches. However this work has to presume the readers understanding of basic physical and biological processes.

Environmental modelling applying state-of-the-art computer tools is the key approach to analyse these processes and to develop indicators to assess of urban environmental qualities, applicable planning aid and indications for legislations and public policies, aiming for sustainable urban transformations considering limited financial possibilities.

Quantifications of benefits (compared to costs) are proposed as a feasible strategy to convince decision makers that the difficult task of introducing more vegetation cover into dense urban structures of tropical megacities like São Paulo is worth its financial effort because it increases environmental comfort, well-being, quality of life, productivity, economical sustainability etc. Literally green and sustainable cities lately seem to have better arguments for their city-marketing, attract tourists and investments (– and thus paradoxically may grow more?)

One could ask: "Who would visit a megacity to see its green?" After all, megacities are "famous" for their literal "endless, grey, concrete deserts", visible from space even with the naked eye and not for their green. They are generally understood as the *Inverse of Nature* and not as parts of it. This image however is changing, because we perceive, beyond doubt and through the enormous changes that we depend on the environment – especially in megacities of the urban age on a globalized planet.

Brazil plays an important role in the global discussion on the preservation and destruction of pristine forest and sprawling urban agglomerations mainly due to events in its *Amazon* region. Generally, the *Atlantic Forest* biome of the south-eastern costal region of Brazil, which surrounds both

[4] Urban morphology means here the actual spatial (three-dimensional) arrangement of buildings, infrastructure and greening as a result of the historical development of the city layout.

Brazilian megacities, São Paulo and Rio, is considered even richer than the Amazon region in terms of biodiversity.

This approach also tries to explore

- ***Past and present:*** The urban-natural history of the São Paulo region (which will be analyzed in the third chapter) witnessed first an intense coffee production which occurred within today's municipal area (as well as in São Paulo state). This period was fundamental for São Paulo's initial economical growth. Subsequently (after 1929) the growing urbanized area showed a strong decrease of the vegetation cover and the sealing of the fertile soils, due to the accelerated urbanization process. Today environmental problems linked to increased urban land-use and decreased vegetation cover become visible and perceptible within the city.

- ***The possible:*** Urban forms of vegetation are manifold: from private gardens to public street trees, parks, ornamental flower beds - as well as in the form of mostly undesired spontaneous vegetation. The integration of vegetation can have negative impacts when interfering with other urban infrastructures and optimizing is a big challenge for contemporary city planning.

  The work analysis chances of an increase of urban vegetation cover in combination with an improved *Urban Forest Management* in the light of the socio-environmental difficulties of megacities in emerging countries, often put forward. The *Urban Forest* concept includes all inner city urban trees, as well as any other private and public forms of vegetation, including (currently still rare) green roofs, facades and sky gardens.

  Analyzing São Paulo's dense and vertical urban structures (like Köhler and Schmidt did the case of Berlin 1996) it becomes clear that (apart from the obvious street trees) noteworthy greening potentials are also principally localized on the building surfaces, their façades and rooftops.

- ***The vision:*** A transformation of the existing cities into *"Disappearing", tropical and vertical Garden Megacities* (as a synthesis derived from Le Corbusier's, Howard's and Wright's early visions, see chapter 3) which would be conceived more sustainable today will probably not "concretize" in the near future but an approximation between environment and human society (within the economical possibilities) is undeniable especially within concepts of (literally?) *"Green Cities"*.

-

Thus apparently paradox, such literally cool *Tropical Green Cities* could hypothetically not cause, neutralize or reverse their negative impacts (footprints) on the environment, be more comfortable, less stressful and more livable. They could decrease social-economical and environmental contrasts and produce more energy, drinking water and food than their inhabitants (and visitors) consume.

Especially the combined (synergetic) benefits of vegetation could be significant at large scale. In hot climates important is that since artificial cooling is expensive and only affordable for limited space, passive cooling through greening is an effective strategy for adapting buildings (and whole tropical cities) for climate change, increasing their energy efficiency.

The architectural formula to cover or "substitute the grey by the green" or "hardware by software" is according to Ambasz (1995) a simple but a deep-going way to develop a new urbanism that does not alienate the citizen from the vegetative area but creates an architecture that is closely interlaced with the green and with *Nature*.

According to Koolhaas (1999) such contemporary visions or ideal cities (e.g. proposed by the so-called *Green Avant-garde*) are less popular today than in the beginning of the modern age because modernism was not able did not keep its "alchemical promises".

Anyhow the recent emergence of an increasing number of literally green urbanistic proposals - from literally green retrofit to whole green new cities - (especially in Asia) is undeniable.

Fig. 1.3: *Future new town of Gwanggyo/ Korea (2008) (above) and Megacity Datatown experiment (1999) both by MVRDV architects Rotterdam*

Method and Limitations

The broad overall aim of the study was to give a panorama on the role of urban vegetation and environmental models to estimate the cost/ benefits relation, as well as a preliminary calibration and application of the models. The main challenge is that the so-called *Environmental Services* ("mechanisms") of urban vegetation act at different scales ranging from local micro-scale (thermal comfort due to tree shade) across regional (improved stormwater management and air, water, soil quality) to global scale (climate change and sequestration of carbon dioxide).

Simulating the dynamics of living systems, urban vegetation canopy and climate change is still very complex even using advanced computer models. At this moment no integrated model exists are capable to make reliable analyses and prognostics of the benefits (see chapter 3), so that various models had to be acquired, calibrated and applied in order to estimate *quantum change* of the *environmental services* or urban vegetation. Especially the dynamic spatial and temporal variations and transformations of the *living systems* are a big challenge when in comes to defining input parameters.

> "Collectively we must come to the realization that there is no exterior to our ecology. There is only one environment and everything is entered on the balance sheet. Every positive, every negative. Everything counts" (Bruce Mau 2004)

Since the capacities and scales of models vary and boundary conditions are difficult to define the concept of "nesting" (from large scale to small scale) is an interesting modeling approach to integrate different models which was applied here integrating the regional scale climate model RAMS with the micro-scale model ENVImet. Another challenge is to re-calibrate models developed (and calibrated) in temperate climate regions by comparing them with local measurements.

Besides from all technical advances, more and more science recognizes its own limitations. Especially the exact sciences learn to accept their limitations concerning temporal-spatial exactness, not least due to the quantum physics. This work therefore has to accept "fuzzy" approximations and estimations as an integral part, due to the complexity of the issue.

Sources analyzed and cited are manifold: Literature research contained scientific articles and guide books (in English, German & Portuguese language), as well as articles (mostly Portuguese) from local newspapers and journals. All quotations originally in German and Portuguese language were translated by the author; citations originally in English language were quoted literally to maintain the original content.

Additionally to literature research, field studies such as measurements of leaf area and climate monitoring (combined with resident interviews) were executed in two locations for calibration of the microclimate simulation tool.

***Fig. 1.4:** Scales and perspectives: Whole Earth Image - Icon of globalized world view [5] with overlay Tropical Belt (above) and Individual open Perception Sphere (below)*

[5] See Martin Heidegger: Die Zeit des Welbildes (Holzwege, 6. Auflage 1980, S. 92) and
Die Geometrie des Ungeheuren – Das Projekt der metaphysischen Globalisierung (Peter Sloterdijk, Sphären II Globen, Surkamp 1999)

Structure of thesis

Since this thesis tends to interlink *everything* e.g. many strongly correlated and socio-environmental issues, a large number of cross-references became necessary. In the following each chapter of this book is presented in a resumed form.

Chapter 1: This indicial, introductory chapter details and justifies why it is worth analyzing especially the environmental benefits of urban vegetation in predominantly warm (or hot) megacities of low latitudes.

Chapter 2: The second chapter presents and discusses essential concepts like *Nature, urban environment/ ecosystem and contemporary indicator concepts of urban quality of life, sustainability and environmental comfort* – all closely interlinked with urban vegetation. Though the chapter can be described only as possible attempt of *impossible definitions* (due to the fuzziness), the importance of these concepts defined rather by individual perception, social disputation seeking for consensuses has to be pointed out explicitly.

Chapter 3: The third chapter presents a brief history of the relation between landscape and urbanism of City of São Paulo focusing on its vegetation from the city foundation until today. This retrospection reveals the outcome of a strong decrease of vegetation cover and at the same time an increase of urban environmental problems due to rapid urbanization during the second half of the twentieth century.

Fig. 1.5: ***Green urban center proposed by Kenneth Yeang***

Chapter 4: This chapter seeks to understand better the complex role of urban vegetation, focusing on plant physiology, the climatic impact of vegetation cover, exchange processes between vegetation and atmosphere and metrics (or parameters) for calculations and especially important for growth simulations.

Chapter 5: The fifth chapter is a critical analysis of the cost-benefit concept, starting from a comprehensive overview on benefits and drawbacks (or costs) of urban vegetation encountered in literature, which also illustrates complexity and conflicts of re-introducing and maintaining urban green in existing cities.

Chapter 6: The sixth chapter explores methods to simulate environmental benefits of the existing vegetation cover and of future scenarios at different scales and with different tools. Special notion is given to the *quantum change* of vegetation on surface energy balance and thermal comfort at micro-scale - e.g. to re-vitalize degraded public spaces in megacities like São Paulo. Further citywide benefits like stormwater management and air pollution removal and global ones like CO_2 sequestration will be analyzed, using a geographical information system (GIS).

Chapter 7: The last chapter resumes and discusses the results and points out that benefits beyond conceivability or even immeasurable benefits exist which are not considered in this book. Further the last chapter gives some recommendations for an improved *urban forest management* as well as *literally green architecture*.

According to an interview with São Paulo based landscape planner Benedito Abbud urban vegetation can mitigate environmental problems but he adds: “Planting helps but does not solve the problem (...) It does not help to plant any tree in any place, because instead of becoming a solution it can become a problem” (Abbud, 2007)

2. ENVIRONMENTAL CHALLENGES OF MEGACITIES

"Since man is the most powerful being on Earth he has to fear nothing more than his own acting." (Weizsäcker et. al. 1995)

This chapter begins with a brief exploration of the contemporary relation between human city dwellers and their urban environment, *Nature* and its fragments. This relation has changed significantly during the 20th century, mainly through rapid processes of industrialization, urbanization and globalization.

A short reflection on the question appears to be important within the context of São Paulo, localized in a country like Brazil, which developed rapidly from a rural country to an urbanized country within the last century. Both immigrant waves and a *national rural exodus* have led to an urbanization rate of 83% in Brazil until today. At global scale more than half of humanity lives in cities since 2007.

According to the *Healthy Cities Program* of the United Nations urbanisation has affected traditional social bonds and cultural affinities: "People are becoming increasingly anonymous in big cities and the sense of belonging to a neighborhood or a city has started to deteriorate. These physical and social factors affect health, directly and indirectly" (see also local research carried out in São Paulo on Health, Well-being and Stress)[1]

Urban vegetation tends to establish a local climatic[2] equilibrium and is *basic need* for local ecosystems. Besides from this environmentally functional aspect it has a symbolical character representing *Nature* in cities: Contact with *Nature* in cities leads, as surveys indicate, to a decrease of stress-related illnesses (see chapter 5.3.2). Especially in urban greens, parks or gardens but as well in green neighbourhoods, we may have the chance to transcend contradictions, recognizing a second (or even umpteenth), designed and cultivated *Nature*, which consists often mainly of ornamental urban gardening and is rarely wild.

Contemporary, *fuzzy* concepts like *quality of life* (QoL), *environmental comfort*, *aesthetics* etc. are often policy goals but according to Constanza (2008) adequate definition and measurement have been elusive. In this approach these concepts are however fundamental because they seek to analyze direct and indirect perceptions of the dynamic environment, as well as consensuses concerning e.g. the ratio of urban vegetation its impact on above-named concepts.

Besides from the wide and general use of the buzzwords *quality of life* and *sustainability*, Köckler (2007) points out the indicators of these concepts (first developed in Europe and the United States) and goals to increase them should be defined and adjusted locally in processes which incorporates citizens.

Fig. 2.1: The surreal collage "Aircraft Carrier City in Landscape" by Hans Hollein (1964) captured a mega-structure as a foreign object with clear boundaries in a natural landscape in one image.

[1] São Paulo Megacity - Pesquisa sobre Saúde, Bem-estar e Estresse Online: http://hcnet.usp.br/ipq/projetos/spmegacity.htm <access on 25th of June 2009>
[2] This refers to the urban water, energy, carbon and nutrient balance

2.1 Concept Nature

Nature often refers to *everything not created by humans* and was sub-divided into *animate* and *inanimate Nature* in the past. The word is used in various societies but often contradictory even within the same society. Today with rapid changes in the natural sciences its meaning is transforming and *Nature* is often perceived rather as a concept and a social construction (see Martínez Alier, 2007, pg. 45), than as creation in the religious sense.

This is mainly because the difficulty with the Nature is that categorical human thinking hardly permits the understanding that the observing human subject is part of the observed object - *Nature*. Kant's *Naturbegriff* stated that we will have to accept an *"as if" status of Nature*, in order to keep the concept of *Nature* capable of discourse, especially when we discuss the "boundaries" between *Nature and Civilization*.

Zendron (1999, p. 240) suggests that the "consequently thought borderline" between *Nature* and *Human Culture* (or civilization) is obsolete today because "nothing unaffected by man exists no longer, at least not on Earth".

Concepts and keywords which underline the "consequently thought borderline" between *Nature and Human Culture* are for example *Bioshphere* (as a synonym for a biotic_natural_wilderness_rural environment) versus *Tecno(urbes)sphere* (which describes an abiotic_artificial_civilized_cultural_urban space), (see Menegat, 2008).

However natural resource systems like soil, water and air - which are intimately linked climate and ecosystems - transcend boundaries and *other mind spheres* and do not exists apart from each other. Climate change may be a good example to illustrate the *fuzzy boundary* idea (see fig. 2.3). For McDonough et al. (2004) the mind spheres are integrated and cannot be observed separately or as an *Addition of Parts*, as common in the natural sciences since René Descartes 1596-1650.

According to Jung et. al. (1964, 1999) Nature can anticipate all of our attempts by directing the inventive spirit of the human being against himself. Jung says that despite our proud mastery over *Nature* we are always victims of Nature, because we have not even learned to keep ourselves under control. It still remains natural for people to fight against each other about priority. Jung concludes with the question "*To what extent did we therefore defeat Nature?*"

Corresponding to Spengler (1922) "it is a quite certain, but never fully recognized, fact, that all great cultures are city-born". Spengler recognized that "the outstanding man of the second generation is a *city-building animal*". Besides from being genetically little different from animals, humans share, according to Sacks (2009), 70% of DNA with plants.

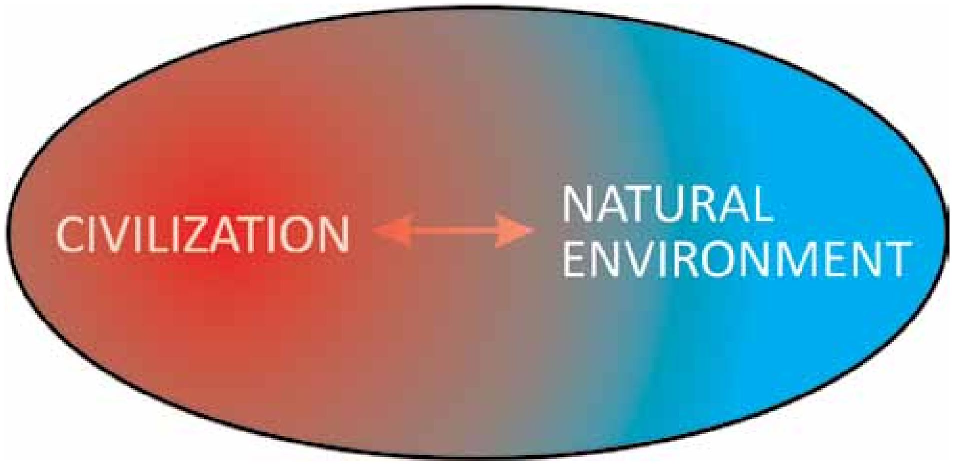


Fig. 2.3: Brainmap of the biosphere, visualizing of the paradox relation between humans and their natural environment. On one hand humans may be able to emancipate from Nature to a certain degree on the other they remain part and dependent on their environment at any time.

The cradles of the "great cultures" (and especially the megacities of the 20th and 21st century) appear often to be the inverse of Nature due to the absence of natural elements and the hegemony of man-made elements, but from another point of view they can be also seen as (nothing more than) a *human-dominated ecosystems* (Rowntree, 1986).

The concept of *Nature* was chosen for the title because it is the most comprehensive all concepts (including soil, water and air, as well as, the intimately linked climate and ecosystems), because vegetation represents *Nature* in (mega)cities as a basic need for urban fauna and the ecosystem in general. American Forests (2002 and 2004) e.g. even conceptualize the *Value of Nature*.

Reflecting and researching about the basic and contemporary concepts especially those of *synergy and retro-innovation* (also represented in the title) appeared striking. Retro-Innovation means here a temporal (and spatial) feedback, in which advantages of traditional, vernacular concepts are recognized, and lead - combined with new scientific discoveries – to new hybrids (see Stuiver, 2006) which is reflected e.g. in concepts like “living machines”, “mimicry” and “bionics”.

2.2 Humans and Environment

According to Mendonça (2002) the history of humanity is a history of the adaptation of humans and their society to the conditions of the physical-natural terrestrial environment, and as well the history of the transformation of the environment through human activities. Today we cannot conceive the reading of (our own) reality only through the perspective of natural or environmental determinism, but the complete denial of the influence of *Nature* on men and his society would also not be acceptable.

Mendonça concludes that to say “that the geographical environment explains all of the psychological dispositions of people" would be (as Sorre, 1984, p. 86 alerted), “as wrong as denying any role of the environment”.

Fig 2.2: Urban structure and culture in São Paulo’s treeless Brigadeiro Avenue (left) and Overgrown abandoned dwelling in Dois Rios, Ilha Grande 2005 (right)[3] (Photos taken by the author in 2007 and 2005).

2.3 Indicators for Urban *Quality of Life* and *Sustainability*

The development of indicators (and indices) to support broad, comprehensive and complex *index concepts for Quality of Life and Sustainability* emerged in the second half of the twentieth century with the censuses and other geographical data acquisition in the so-called developed counties. One of the aims of censuses was to measure the quality of living conditions of populations rapidly increasing in numbers and limited by natural resources e.g. space.

The aim of defining *indices* which reflect *quality of life* and *sustainability* by weighting various indicators statistically is a contemporary approach to understand and monitor socio-economical and environmental development at different scales (household, neighbourhood, district, city, country, state).

It has to be pointed out that these indicators are only (temporally and spatially) limited *means to an end, benchmarks or agents* (Köckler, 2007) which allow (or simplify) the assessment of the concepts which they represent. According to Jensen et. al. 2004, the growth and expansion of these concepts within and across the economic and regional development literatures is undeniable especially in the Americas.

Complex phenomena like the *quality of life or sustainability* cannot be observed directly and not be defined generally but are important in the discourse because they introduce new forms of environmental rules and regulations as well as alternative strategies and tactics to mainstream environmentalism (Jensen et. al., 2004).

Although indicators are often derived from standardized censuses (in Brazil by the IBGE[4]) according to Köckler (2007) in an ideal process, issues important to the local population need to be discussed in participatory *processes*, to achieve *consensuse*s. This is especially important in cities which seek to customize and to adopt concepts of *quality of life* or

[3] The apparently inevitable scenario of man disappearing from the Earth’s surface and subsequently spontaneous vegetation recovering the surface is an issue covered by the History Channel’s documentary “Life after People” (2008)
[4] Instituto Brasileiro de Geografia e Estatística, www.ibge.gov.br/english/ <access on 26th of June 2009>
[5] In emerging and developing countries environmental issues like equity play, according to Alier-Martinez, important underrated roles which seem not to be recognized by the population yet, as discussed later.

sustainability developed first in northern countries[5], were living conditions are generally different.

Indicators like *Green space per Inhabitant in Square Meters or Trees per Inhabitant* are included in the *Sets of Indicators* of many cities to measure (or indicate) their urban *quality of life*, *environmental quality* and/ or *sustainability*. The indicators for urban vegetation as well as measurements of metrics will be described and analysed in more detail in section 4.2.

Generally *indices* which include *environmental indicators* recognize and valorise amenities, services and environmental comfort provided by vegetation cover (see Jensen et. al. 2004, Robba and Macedo 2003), alongside with typical indicators like alphabetization rate, child mortality, income etc.

The addition of indicators to measure inequality e.g. social-environmental In- and Exclusion, urban violence, usually measured by homicide rates, etc. is recommended especially in the large urban centers affected by harsh contrasts.

Quality of Life versus *Sustainability*?

Literally hundreds of *indicators* and *indices* have been developed world-wide but often it is not clear whether they are based on the concept of *quality of life* or that of *sustainability*. Although rarely discussed there is an important contradiction between the concepts of *quality of life* and *sustainability*: the concept of *quality of life* tends to focus rather on the *individual well-being* or that of local interest groups than on the broader well-being (or even survival) of the global society, like the concept of sustainability (Köckler, 2007).

The clearest examples of indicators for *quality of life* developed and applied in western societies are income (the higher the income, the higher the *quality of life*) and for example number of cars per inhabitant (the higher the number, the higher the *quality of life*).

That *quality of life* and *sustainability* are, depending on their definition, not necessarily contradictions can be illustrated by the example of the City of Portland (United States) which was one of the first cities to develop indicators for *quality if life* (*Oregon Benchmarks* 1988-90, see Köckler, 2007) and has become, according to a *US City Rankings* (2008)[6], also the most sustainable.

Various indices for *quality of life* like the *Municipal Index of Human Development* (IDH-M, 2000) and the *Living Condition Index* (ICV, 2005, 2007)[7] based on indicators for longevity, education, income[8], child-mortality and housing were estimated for São Paulo based the censuses of national *Brazilian Institute of Geography and Statistics* (IBGE), which derives, monitors and publishes statistical information in cooperation with the São Paulo *State Agency for Data Analysis* (SEADE). Although these indicators are showing correlations with environmental indicators (see fig. 2.4) they hardly consider physical indicators of the urban environment.

Since 2004 the common indicators in São Paulo also include global Indicators for *Sustainable Development* (see IBGE). Sustainable development is - although first mentioned by agronomist Carl von Carlowitz in 1713[9] in the forestry context - a concept which developed much slower than the more popular one of *quality of life*. Sustainability in fact was not properly defined before the *Brundtland Report* (Brundtland et. al., 1983), which again was a late outcome the *Club of Rome's The Limits To Growth*[10], (compiled by Meadows D.L. et al., 1972) and the *Stockholm Conference* in 1973.

The main content of the concept is to analyze the impacts of human acting - from the local environment and to global scale - and the conservation of livable conditions for our own future and that of future generations (our children).

The *Rio Conference* (hosted in Brazil in 1992) was another important intercept for the global development of the concept but many observers found in practices little had changed globally after a decade, except from some citizen-orientated *Local Agendas 21 defining Millennium Development Goals*, which developed principally in Europe and the United States.

Since sustainable development intends to integrate the social, environmental and economical development it has often been described as *Utopia* because to many it does not seem viable that the planet's resources support the increasing needs of its population due to the still strongly increasing number of inhabitants due to the global failure of birth-control and continuously strong local variations of life-style.

Indicators and Indices for São Paulo

The most comprehensive resources available on the state and outlook of the urban environment in the case study City of São Paulo are resumed in the following. The selected reports include or focus on environmental data and indicators, e.g. vegetation cover:

- ***The Atlas Ambiental do Município de São Paulo (2000)***[11] (Environmental Atlas of the City of São Paulo) was

[6] www.sustainlane.com/us-city-rankings <access on 26th of June 2009>
[7] The ICV was applied nationally to compare quality of life in Brazilian State Capitals. São Paulo ranked only the 11th position between 26 Brazilian 2005, http://www1.folha.uol.com.br/folha/dinheiro/ult91u101796.shtml <access on 26th of June 2009>
[8] The Municipal Index of Human Development considers "a decent standard of living measured by income" as a high quality
[9] Carl von Carlowitz (1713) Sylvicultura oeconomica, oder haußwirthliche Nachricht und Naturmäßige Anweisung zur wilden Baum-Zucht
[10] Including early computer simulations and prognostics of future global development by the MIT and the University of California
[11] http://atlasambiental.prefeitura.sp.gov.br/ <access on 26th of June 2009>
[12] http://atlasambiental.prefeitura.sp.gov.br/pagina.php?id=25 <access on 26th of June 2009>
[13] www.unep.org and www.pnuma.org/brasil/geo-saopaulo.pdf PNUMA/ UNEP (GEO - Global Environment Outlook) is a project which started in Brazil with the PNUMA (Programa das Nações Unidas para o Meio Ambiente) <access on 26th of June 2009>

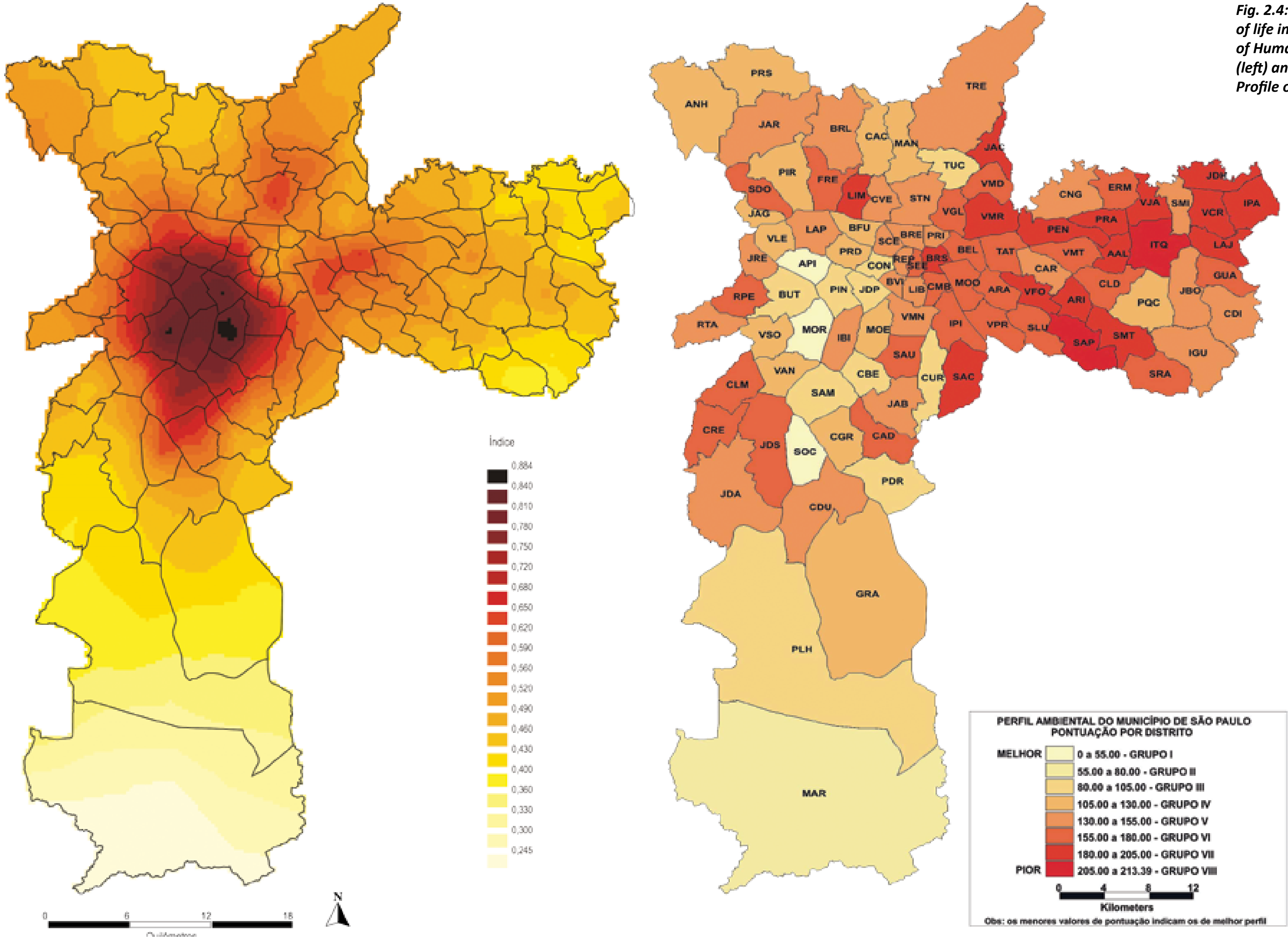


Fig. 2.4: Indices for quality of life in São Paulo - Index of Human Development IDH (left) and Socio-Environmental Profile of the SMVA (right)

developed by the *Municipal Secretariat of Green Areas and the Environment* (SVMA) and the *Municipal Secretariat of Urban Planning* (SEMPLA) of the *City of São Paulo* as an interdisciplinary project also developed in cooperation with the *University of São Paulo* (USP). The atlas analyzed for the first time environmental issues like vegetation cover, urban climate, and socio-economical environment in a comprehensive way, applying a geographical information systems (GIS) at a city-wide scale. The atlas e.g. includes an index named *Socio-Environmental* Profile[12] which integrates the three environmental indicators of *Distribution of Vegetation Cover* (1999), *Deforestation during the period of 1991-2000* and *Surface Temperature* (1999) with one socio-economical indicator based on income to indicate *quality of life* and *sustainability* per district.

- ***The GEO-Cities Report for São Paulo (2002)***[13] was elaborated under the supervision of the *United Nations Program for the Environment* (UNEP/ PNUMA) based on the *Pressure -> Space -> Impact -> Response* model methodology developed by the *Organisation for Economic Co-operation and Development* (OECD) which is applied for cities world-wide. The São Paulo report was developed in cooperation with the local institutions

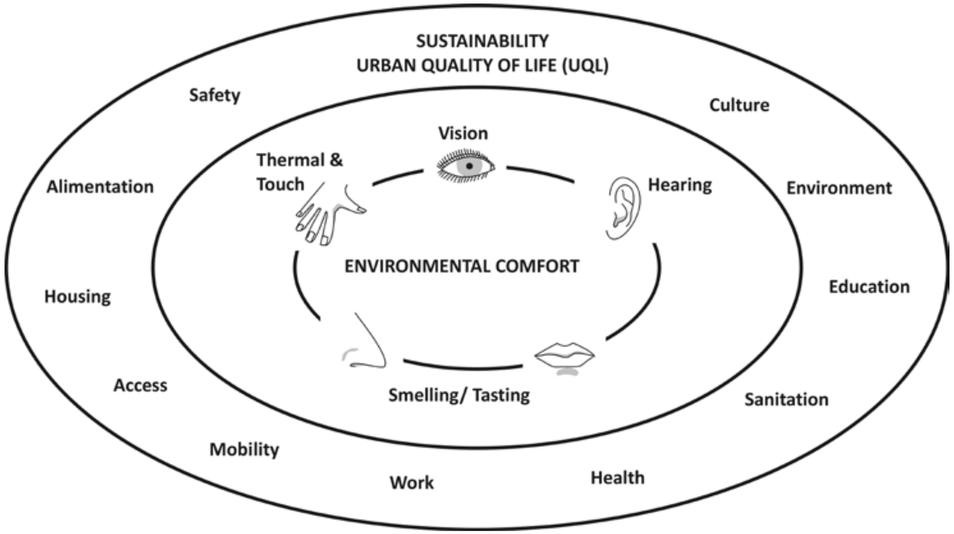


Fig. 2.5.: Environmental comfort as a central and direct (benefit) issue in the discussion on urban Sustainability and Quality of Life.

Sense Organ	Sense	Ability	Indicator unit
Eye	SIGHT	Shortwave radiation (light) reflected on surfaces/ shade	[Lux]
		Material properties (Colour, relief etc.)	
		Three-dimensional appeance of the space	[mm,cm,m,km]
		Reading/ visual communication	*Surveys*
		Aethetics	
Skin	SENSE	Touch, relief, surface temperature & humidity	
		Thermoception (hot/ cold), perception of liquids (air/ water, etc.) and solids	e.g. PET, PMV
		- Solar & thermal radiation (longwave, diffuse & direct)	[W/m²]
		- Wind	[m/s]
		- Air Temperature	[°C]
		- Humidity	[%] or [g/kg]
			Surveys
Ear	HEARING	Verbal communication	dB(A)
		Noise and silence	*Suveys*
		Harmony and disharmony	
Nose	SMELL	Stink - unappetizing	*Surveys*
		Scent - appetizing	
Mouth	TASTE	Appetizing	*Suveys*
		Unappetizing	
		Verbal communication	

Table. 2.1.: Overview of the human senses and sense organs as interfaces with the environment, between in and outside (based on Behling 1996)

[14] http://sempla.prefeitura.sp.gov.br/urb_pde.php <access on 26th of June 2009>
[15] www.nossasaopaulo.org.br/portal/files/agenda2012.pdf <access on 26th of June 2009>
[16] www.urban-age.net/0_downloads/SANewspaper-UrbanAge_City_Survey.pdf <access on 26th of June 2009>

IPT (Institute of Technological Research) and the SVMA (Municipal Secretariat of Green Areas and the Environment). The *Global Environment Outlook* (GEO) report focused on the urban environment and analyzed its state.

- ***The Strategic Masterplan of the City of São Paulo (2002)***[14] (*Plano Diretor Estratégico do Município de São Paulo*) is the city's first masterplan and seeks to regulate the future urban development and transformations to increase urban *quality of life*. It defined general goals to increase the number of *street trees* and *green areas significantly* and proposed the implementation of a regional system of *linear parks* until 2012. A recent actualization (2009), the *Agenda 2012* [15], promises the implementation of 50 linear parks and 800,000 trees.

- ***The Urban Age City Survey (2007)***[16] was a survey on the actual *quality of life* in São Paulo carried out by Oliveira and Page for the *Urban Age Congress* held in São Paulo in December 2008. The aim of the survey was to detect key challenges analyzing public and expert opinions. While environmental issues were not even recognized by the public, they appear as one of the less important issues in the expert opinions after transport, housing, crime. Only 13% of the interviewed local specialists believed that the better environmental conditions could improve *quality of life* in São Paulo. In comparison in London 51% of the specialists considered the urban environment important. Interestingly - and much in contrast to European experts - the loss of green areas and vegetation cover (15%) as well as climate change (8%) were among the environmental issues which concerned São Paulo specialists least.

- ***The Basic Indicators of the City of São Paulo (2009)***[17] study was carried out by the NGO *Nossa São Paulo*. It analysis 33 basic indicators (of 140 available) which are internationally accepted references as indicators for good *quality of life* for each of São Paulo's 31 sub-municipalities (districts). One of the environmental indicators is square meters of green area (with more than 900m² of continuous vegetation cover, see also fig. 6.12). The study introduces a so called "Desigualtômetro" ("Inequitymeter") which is the factor of inequity between the best and the worst indicators above zero. It shows for the *Green Areas Indicator* one of the highest inequalities of 176.3 times of all 33 basic indicators analyzed.

2.4 Environmental Comfort

Besides from the indicators for *quality of life* and *sustainability* it appears to be important to draw attention and to give a short introduction on the even

Fig. 2.6: Two examples of a new urban environmental sensibility in literally green cities with vegetation shade for thermal comfort: Expo Sevilla Spain in 1992 (above) and Brisbane/ Australia (below)[19]. Other cities which incorporated new urban environmental sensibility are among others Sacramento in the United States and Singapore in Asia.

[17] www.nossasaopaulo.org.br/portal/files/CadernoIndicadores2009.pdf <access on 26th of June 2009>
[18] This applies for most of daylight time in the tropics. It is pointed out that the energy flux (heat transfer) is inverse to the heat flux in Europe in the cold seasons.
[19] Conference on Subtropical Cities in Brisbane, Australia at the Queensland University of Technology.
Lessons from Brisbane - Shade everything, including buildings, especially the sidewalks, New Subtropical Streetscapes: shadows http://picasaweb.google.com/maruglenn/LessonsFromBrisbane <access on 26th of June 2009>[21] http://hcnet.usp.br/ipq/projetos/spmegacity.htm <access on 26th of June 2009>

more immediate, local, anthropocentric concept of *environmental comfort*. The concept is approached here based around sensory perception, sensual comfort and adaptation but it can be explored on a much broader basis of moods and very individual perceptions resulting from the complex flux of information and stimulations the brain receives (especially in cities), such as feelings of danger or safety, boredom, enjoyment, creativity etc. (Behling, 1996).

The broad concept of *environmental comfort* is based on human physiology and psychology. Thus human well-being, productivity and efficiency are influenced by the environment. When São Paulo's most famous architect Paulo Mendes da Rocha states (in an interview with Bravo! in 2006), that he desires a more *sensitive* (or even *erotic*) city he makes a direct reference to sensory perceptions of the city environment. The following section discusses in how far these aspects are recently considered and discussed in São Paulo and world-wide and in how far they have entered the local legislation:

Visual Comfort

It is often mentioned that the vision is the primary sense organ of humans and also that it is widely over-rated. As a city-wide political action, in São Paulo, the municipal law No. 14.223 *Cidade Limpa* (Clean city), inured on 01st of January 2007, prohibits so-called *visual pollution*, for example in the form of billboards (so-called *outdoors*). According to the municipal law, these used to be very popular, hiding the historical heritage of the city. Both architecture and urban green is mentioned in the public discussion to increase urban aesthetics. The implementation of the law was executed with an unexpected rigidity, so that the city is today (May 2009) almost free from billboards and other outdoor advertisements.

Other important aspects of *visual comfort* are glare (e.g. due to highly reflective glass facades and other urban surfaces), as well as *daylight* access in partly extremely obstructed, dense urban situations, which leads to increased electric energy for artificial lighting and cold stress in winter (discussed in chapter 5.2.2).

Thermal comfort

Thermal comfort is directly linked to luminous comfort (see 5.2.2 and 5.3.1) a necessity of climate adaptation and energy efficiency, thus one of the most important aspects of urban sustainability in cities of predominantly hot climate. This applies as well for the quality of open, public spaces (urbanism) as for the inside of buildings (architecture) because the thermal acceptability of public, surrounding spaces is indirectly linked to energy consumption for artificial cooling through heat transfer from outside to inside[18].

Improving energy efficiency of buildings is incentivized by green building certificates e.g. LEED[20], and assigned in São Paulo since 2007. The energy (and cost) efficiency of generating thermal comfort is expected to enter the national building codes in the form of the first energy conservation legislation in Brazil, expected for the future.

The multiple and complex reciprocal relations between outdoor, urban and indoor climate and the impacts on energy consumption in the tropics have been made by various authors (Alucci 2006, Taha, 1997). The human skin has a surface area of approximately 2 square meters and is, in physical terms, the largest sense organs of humans (see table 2.1.). Thermal comfort is also a central issue in the light of climate change, of urban climatic adaptation and thus in this work. The isssue will be discussed explicitly in chapter 6.2.1.

Acoustic comfort

Caused mainly by massive transit, urban air borne noise is (associated with air pollution) an urban problem, which only recently gained notoriety in Brazil. In São Paulo especially linked to an overfly nick-named *Minhocão* (=Earthworm) built in 1985. The viaduct led to a further loss in value of real estate properties in the city's central region. Urban noise is (besides from increased ambient temperatures and air pollution) the argument most often assigned for the decision to construct air tight building envelopes and apply HVACs (especially for typologies like office buildings, shopping centers etc.) instead of applying bioclimatic building principles based on natural ventilation and shading which was the traditional standard solution. This results in the problem that thermal and acoustic comforts of indoor ambiences are intimately linked to each other and means that transport, thus noise and air pollution problems, need to be solved first to allow naturally ventilated buildings again.

Olfactory comfort

Scent and the taste convenience either are closely linked to each other: Mautner (2003) reflects about smell characteristics of São Paulo, also linked to food. Mautner is a local and remembers and reminds how rich the *worlds of scent* (and indirectly taste) of São Paulo were in the past, before the city became adapted purely for cars. The author mentions the smells of the coffee roasting facilities, the bakeries, the pizzerias, as well as rural smells from the (still clean) rivers, the Eucalyptus trees in Ibirapuera park and from the saw mills.

Mautner concludes that today cars and buses keep the citizens away from the city smells; even though these sources of scent still exist, they are additionally overlapped by artificial sanitary products which remove people from natural smells. The author concludes that it seems that the olfactory sense underwent the biggest changes of our five senses, although this is hardly mentioned. Additionally it is undeniable

[20] Leadership in Energy and Environmental Design (LEED) Green Building Rating System www.usgbc.org/LEED
[21] http://hcnet.usp.br/ipq/projetos/spmegacity.htm <access on 26th of June 2009>

that bad smells that from polluted rivers, garbage on streets and emissions from vehicles locally contribute to the rather insensitive environment of the mega-metropolis of São Paulo.

Generally speaking, the often high levels of disturbing factors, and their combination, tend to lead to *stimulus satiation*, distress and often a stressful urban environment, which has direct influences on urban quality of life and health (see São Paulo Megacity - Pesquisa sobre Saúde, Bem-estar e Estresse[21])

Environmental Comfort relies additionally on other, highly subjective, psychological sensations, which are difficult to grasp, or even to quantify. Among those also are important issues in cities like São Paulo are aspects like safety of public spaces, especially at night, due to urban violence, access to transport, health, education, culture, alimentation, sanitation, housing etc. (see fig. 2.5)

The research carried out on artificial and partly restricted spaces of *shopping centers* (see chapter 3) serves as a good example to prove the general importance of environmental comfort due to the major attention which is paid to the satisfaction of all the five senses of the consumers in order to offer the best "climate/ atmosphere" to sell commodities. Especially in hot cities in developing countries thermal comfort, as well as, safety are the key elements of the success of *shopping centers*.

Fig. 2.7: Two example "Non-Places" in São Paulo: Driveway of Octavio Frias de Oliveria Bridge (above) and the End of the footpath at the Consolação - Paulista Avenue crossing (below)

2.5 Places and Non-Places

The anthropological concept of *Places and Non-Places* by Augé (1994) describes urban transitorial places which do not invite pedestrians for strolling and/ or permanence or for any engagement and appropriation with the *place*, as *non-places*. In contrast places invite pedestrians for temporary stays and/ or to rest but these are, still according to Augé, shrinking throughout cities.

The concept can be enhanced here to those public spaces (or places respectively) that are not pedestrian and cyclist friendly, abandoned although dangerously exposed to traffic, noise and air pollution. Places which do not offer *environmental comfort* or *quality of life*. Places that are not designed *sustainable*. Places that are in São Paulo often labeled with *No pedestrian trespassing* signs (see fig. 2.7)
Of course urban vegetation is not the only mean to turn non-places places, to create environmental comfort and quality of life, but correctly planted and maintained urban green appears to be a key element to improve the quality of the environmentally degraded public space, in hot megacities especially due comfort generating shade.

3. CITY VERSUS FOREST

This chapter describes the process of land occupation and urbanisation in the São Paulo region since city's foundation until the present and attempts to constitute an adequate contextualisation for the better understanding of the socio-economical dynamics and today's socio-environmental conditions and challenges.

Obviously this dialectic approach, which looks deeply into the historical relations between city, dwellers and natural environment, points towards a future synthesis between the natural and the built environment in a yet untold natural-cultural history.

This chapter summarizes the civilizing background, since the mythical discovery of the South American continent, the "Rumors of the Paradise", the early beginnings of "civilization" and the first settlements in a vast and densely vegetated tropical clime, sparsely populated by partly cannibalistic indigenous people who wore no cloths.

Subsequently it approaches the foundation of São Paulo in 1554 and the slow urban development until the dawn of the modern age focusing on the loss of vegetation cover, the relations between accessible public and private spaces (which developed differently from the European perception in Brazil) and the genesis of the phenomenon of urban landscapes versus natural landscapes.

Fig. 3.1: Between Past and Future - Original Indian Tupi Oca dwelling (above) and modern interpretation of the Oca by Oscar Niemeyer in São Paulos Ibirapuera Park 1950 (below)

3.1 The historical Roots and the Brazil Tree

Cave-paintings and pottery art works prove that the costal region of the territory named Brazil today was populated for at least ten thousand years before arrival of the Portuguese discoverers. Constructed signs of these civilizations are e.g *Sambaqui*s and *Ocas* (Lacerda 1985).

Shortly after the discovery of the American Continent in 1492 by Columbus, the Portuguese and Spanish crowns decided, motivated by the church, the *Division of South America* by signing the *Contract of Tordesilhas* (1494). When the Portuguese discoverer Pedro Álvares Cabral and his fleet landed on the South American coast, on 22nd April of 1500, at a tropical beach , located North of were the city of Porto Seguro (Bahia State) is located today, he appropriated of the land on behalf of the Portuguese crown and named it “Ilha da Vera Cruz” (Island of the True Cross).

Pedro Álvares Cabral’s writer Pêro Vaz de Caminha wrote *„Se planta tudo dá”* (Whatever one plants grows) in a famous letter to the Portuguese King. Two years later the navigator Américo Vespúcio reported on another expedition off the southeastern Brazilian coast: "If the paradise exists here on Earth - I am surely close".

Fig. 3.2: Pristine Atlantic Forest in a Valley of the Costal Mountain Range by Jean Baptiste Debret (1768-1848)

Subsequently these myths, like fertility of the soil and abundance of the forests became (like in many colonized tropical countries in South America, Africa and Asia), harmful to the aforementioned paradise (or *eldorado*), its forests and the apparently exhaustless natural resources covered by the apparently endless forests.

For Macondes (2006) it is clear that since the first settlers arrived from Europe people perceived Brazil as a marvelous country were “man can be plainly happy and little work due to the abundance of natural resources – exhaustless and to anyone’s disposability”. It is often claimed that the Portuguese travellers- much in contrast to the mainly British North American colonization and the Spanish Latin American colonization - came to only explore the resources of the *New World* but not to stay and to settle (Bartelt, 2008).

Named “Costa de Descobrimento” (Discovery Coast) in the State of Bahia in ISA 2008, p. 195

The most common explanation of the countries name Brazil is, that it was named after the Brazil tree (*Caesalpinia echinata Lam*.) which contains a bright red pigment, used first by indigenous people for ritual face painting. Unknown to the Portuguese until the discovery, the Brazil wood was the first resource exported to Europe as ink and for dyeing cloths (followed by other, then exotic and rare luxury goods, such cane sugar, coffee, rubber etc.). Interestingly, according to this version, Brazil is the first - and only - country named after a tree.

The social history and the background of the country's name is e.g. covered by Sérgio Buarque de Hollanda (1902-1982) in his 1936 book with the ambiguous title "Os Raizes do Brasil", (which can be translated literally either to "The Roots of the Brazil Tree" or to "Brazil's" Roots") and the 1959 book "Visões do Paraíso" ("Visions of the Paradise").

The origin of the Portuguese word *Brasil* again derives originally from the word *Brasa*, which means ember and ember-red. From the 16th century onwards the first Brazilians (*Brasileiros*) consequently were the people who traded and exported the Brazil wood. The exportation of the Brazil wood marked only the beginning of the intensive exploitation of the rich forest resources; including the minerals it covered (Macondes, 2006).

The Portuguese colonization and the founding of the first settlements took place along the costal Brazilian clime, which was then widely covered by the Atlantic Forest biome (*Mata Atlântica*). It consisted of dense tropical and subtropical forests, which stretched along Brazil's Atlantic Coast from the Northern state of Rio Grande do Norte to the Southern state of Rio Grande do Sul. The Atlantic Forest Biome is the biome to which the Brazil tree belongs and is, in terms of biodiversity, considered even richer than that proper Amazon Forest.

Although partly regarded as a valuable raw material (due to extraction of the Brazil Wood[2] by Natives and *Brasileiros*) during the first phase of the colonisation the impenetrable forest was regarded mainly as an antagonist (or obstacle) to reclaim land, for civilization and progress. Especially the Portuguese's crown which allocated large strips of land (so-called *sesmarias*) from 1523 on to Portuguese noblemen recognized deforestation as an act of appropriation and apparent land use which was responsibility of the leud.

Like in many colonized counties covered entirely with tropical rainforest parts were felled or fire cleared and former forest land became more valuable than land covered with standing forests. This means that since the beginning of the colonisation process deforestation resulted in richness due to "cultivation" or use of land.

Exploring this costal region, in which the megacity of São Paulo is located today, has laid the foundation for Brazil's wealth but on the other hand by today 93% of the genuine Atlantic forest has been destroyed and is irrecoverable due to the massive exploration and land-use change. The process has lead to fragmentation and degradation of ecosystems and landscapes, leaving behind literally hundreds of forest islands often on hilltops.

3.1.1 Colonization until Modernization (1554-1915)

The settlement and later the city of São Paulo (Portuguese for "Saint Paul") has, like most Brazilian cities, literally grown out of the jungle. The Jesuit padres Manuel da Nóbrega and José de Anchieta founded a mission at latitude 23º32'53" S longitude 46º37'57" W[3] on 25th of January 1554, after clambering the costal mountain range with guidance of Tupi-Guarani Indians from São Vicente (founded in 1532), when they reached the continental plateau (*Planalto de Piratining*a).

One of the main advantages of the location at almost 800 meters above sea level in the sylvan hills of the *Serra do Mar*, was that it is climatically considerably more temperate than the costal clime (Levi-Strauss, 1952). The *tropical climate of altitude* is at an average 3-6°C cooler than the costal climate. Another reason to settle was that the water supply on the high plateau from the three rivers Tietê, Pinheiros and Tamanduateí (all flowing inland) seemed guaranteed.

According to Murillo Marx (cited by Robba and Macedo, 2003), the Brazilian colonial cities were founded always as a result of a charter of an allotment for a certain saint, with the subsequent construction of a chapel and the establishment of a parish to worship him.

With the tiny settlement which would only 400 years later grow to megacity status began a new local relation between man and the surrounding, the exuberant nature of an entirely new environment, especially due to the fact that the two padres had come originally from Portugal. It is obvious that this initial human settlement refrained from its surrounding tropical jungle due to dangers from poisonous animals etc. McDonough *et al*. (2002) point out, that it should not be forgotten that people had struggled for thousands of years to maintain the boundaries between human and natural forces and that to do so was often necessary to survival.

Consequently the first construction in São Paulo, the mission of the *Pátio do Colégi*o, and its annexed open space followed the common urbanistic principle applied in most South American cities: the indicial creation of a central Patio (also called *parish, largo, terreiro, piazza or plaza* in Europe). These plazas located vis-à-vis front side of the church or mission (and their extensions) were so-called *dry spaces*[4], (*praças secas*) which were free from any vegetation to represent civilization and mastery and to serve

[2] The use of wood is regarded as a direct benefit (see chapter 5.3.1) in contrast to slash-and-burn reclaiming land

[3] Instituto Geográfico e Cartográfico – IGC

[4] Robba and Macedo (2003) define "dry spaces" (also "largos", "pátios" or "terreiros" in Brazilian Portuguese), as what is called "piazza" and "plazas" in Europe while "praça" referres to "squares" which are usually associated with vegetation. According to the authors in Brazilian cities, any town green, whether with trees or just grass, the central median strip of an avenue or the empty space between buildings is called "praça" (square).

for assemblies. Levi-Strauss (1952) remembered that the beginning of the 20th century many of these dry *Patios* especially in many small Brazilian towns had often remained unpaved, rammed earth, overgrown with grasses and herbs.

The central spot was reserved for the chapel/ mission and the *parvis*, while the spaces surrounding it became cemetery and common farming grounds. In contrast to cities of the Spanish colonization which were built based on pre-elaborated drawings which were usually regular grids, the Brazilian cities grew “somehow more improvised, unplanned and centrifugally”, as a result of the founding of parish or religious brotherhood. Streets yards and squares configured themselves based on the construction of rows of houses, resulting in crooked, narrow streets[6], which converged to the central building of the settlement (Robba and Macedo, 2003).

Fig. 3.3: A change of construction methods and materials from leafs to adobe[5]: The point of origin Patio do Colégio in São Paulo (left) and shelter of native Indians constructed of palm leaves (right)

Traditional Construction Methods

The Portuguese colonization had imported its own traditional construction methods from the Iberian Peninsula, but in tropical Brazil soon the necessity of the climatic adaptation of the buildings was recognized. The size of the country and the large variaty of its climates and ecosystems created many adaptations of vernacular, traditional construction methods, influenced by immigrants that came from all over the world and from all climate zones. The prevalent building materials were local, organic materials, especially wood, leaves and clay (Weimar, 2005).

This type of buildings and urbanism would be called *bioclimatic* today, since no heating and cooling facilities were available at the time. The temperature inside of these naturally ventilated buildings was virtually the same as outdoors. However, building envelopes were fulfilling the basic human needs of shelter from the elements of rain and solar radiation, allowing privacy, security and natural ventilation. Especially worth mentioning is the *Muxarabi*[7] facade element, which was incorporated by the so-called *Portuguese Colonial Style*. It came originally from the Arabian regions and was later later via Portugal imported to Brazil (see Spangenberg, 2004).

The Garden in the Brazilian Colonial City

> “In ancient days, the garden was a space devoted to meditation and contemplation, even though this nature might be a human imitation of a wild environment. The garden represented a metaphor of Eden, attracting the image of paradise and heavenly peace.

In Europe, the end of the 18th century witnessed the appearance of the first landscaped areas, meant for collective use. Those were the first public promenades, which kept characteristics of the palace gardens as areas meant for contemplation, mediation, strolls and enjoyment of open-air pleasures.

Rarely found in Brazilian colonial cities, the gardens were limited to religious properties or to the yards of residences, intended for utilitarian purposes. They consisted mainly of fruit trees, vegetables and medical plants. They

[5] Both materials are toady often considered more sustainable than industrial building materials used today
[6] This colonial urbanism in its vernacular tropical adaptation, based on tacit knowledge, represented low Sky View Factors creating maximum building shade and thus thermal comfort (see 5.3.1) while shade trees were sparse in this urban model, which left over little space for planting due to the narrowness of the streets
[7] The Arabian Muxarabi element came to Brazil via Portugal and was used in colonial architecture and later re-discovered by modern architects like Lúcio Costa and Lina Bo Bardi

were meant to support the kitchens and in the yards, used as vegetable gardens and for other services". (Robba and Macedo, 2003).

During the 18th century São Paulo remained a rather unimportant small colonial village. However, it became an important base of expeditions of the *bandeirantes* (flag bearers) into the hinterland (interior) for land occupation, to enslave Indians and seek for the exploration of mineral resources.

During the 19th century Brazil important political changes occurred: Brazil became independent from Portugal since the royal family fled threatened by the invasion of Napoleon to Brazil. Soon the first books were printed in the capital Rio de Janeiro from 1808 on. Interestingly the first book printed was an assay of the royal physician Manuel Vieira da Silva (1808) on the improvement of the climate of the city of Rio de Janerio[8]. The independence was declared in 1822 by Dom Pedro I in the fields of Ipiranga near São Paulo. By today Ipirangá became a district of the city.

City and Landscape

At the end of the 19th century the city was still very compact. Although it had no city walls there were clear boundaries between urban and rural land use. Meanwhile agricultural use had lead to deforestation around the city especially since coffee cultivation reached São Paulo from the Rio-Paraiba-Valley from 1850 on due to the favorable climatic and soil conditions and the growing railroad network which connected inland, São Paulo and the sea port of Santos.

The fragmented landscape forms are called *Campo limpo* (Clean Field) and *Campo sujo* (Dirty Field) in Brazil and refer to the remaining vegetation cover. The French ethnologist Claude Levi-Strauss who lived and researched in São Paulo reflected about the landscape near São Paulo in his 1953 book *Sad Tropics*:

> "This landscape confuses the European traveler because it does not fit into none of his traditional categories. We do not know any pristine nature, our landscape is ostentatious subdue to man […], we are confused with the natural ferocity of the landscape which is the result is a long series of unconscious initiatives and decisions. One has to travel America in order to recognize that this sublime harmony is not at all spontaneous expression of the nature but comes from agreements that were gained in long cooperation between landscape and human being […].
>
> Nature, which was tamed so remorseless, that it reminds rather an industrial site than a landscape. (...) In the surroundings of São Paulo, I learned to become familiar with a nature that is more brittle than ours because it is less populated and less cultivated, but nevertheless the true freshness is missing: a Nature, which is not wild, but downgraded.
>
> Barren lands, as large as provinces humans once possessed here but soon he moved on. Behind itself he left a battered ground full of ruins. And on these battlefields, on which he has fought with an unknown earth for some decades, slowly new, monotonous vegetation[9] begins to sprout" (Claude Levi-Strauss, written in 1935, published in 1952)

Fig. 3.4: View near São Paulo painting by Henry Chamberlain circa 1819-20 shows the widely deforested grounds east of the center with swamp areas of the rivers Tiête and Tamanduateí and the Cantareira Mountain Range in the background.

Urban Green

The New World – especially Catholic America – built its first public gardens contemporaneously with Europe. In São Paulo the former Botanical Garden, which first had not been intended for public use and fulfilled only the function of investigating the native flora, for scientific and commercial purposes was transformed into the city's first public park - *Parque da Luz* - in 1825.

> "The construction of the first public parks turned the import of this model of space from the European cities into a fact, although the differences between the Brazilian and European societies led to the failure of the park. The non-existence of an urban bourgeoisie which needed that non-official space for its demonstration, besides the multiplicity of uses allowed the colonial squares and plazas.
>
> At that point there was incipient urban elite who would eventually frequent public gardens, consolidating in Brazil the European custom "stroll" and the "parade", which motivated the construction, the motivation and maintenance of urban gardens and promenades […].
>
> Landscaped areas became a significant element in the complex of buildings and open spaces in Brazilian cities. Such changes bred a new habit: landscaping. The population began to value the use of plantings for the beautification of streets and part of their yards, now named gardens" (Robba and Macedo, 2003).

The second half of the 19th century saw great changes of the Brazilian society with

[8] Manuel Vieira da Silva (1808) Reflexões sobre alguns dos meios propostos por mais conducentes para melhorar o clima da Cidade transcribed in "Hygiene da cidade do Rio de Janeiro", ABN 1 (1876), p. 187-190. http://blog.controversia.com.br/2008/04/22/diagnostico-do-rio-do-seculo-19/ <access on 26th of June 2009>

[9] called Capoeira or secondary forest

the abolition of the slaves and the definition of private absolute property regulated by the *Lei das Terras*, Law nº 601/1850 which had been developed by Wakefield 1849 in England and superseded the *sesmarias*.

The first republic in 1888 changed the immigration policy to guarantee the necessary number of workers of the coffee plantations and in the emerging industries. Especially the São Paulo region received great fluxes of immigrants, mainly Italian, Portuguese, Syrian, Lebanese, Jews and Japonese. These urban workers began to settle in the new districts of Lapa, Bom Retiro, Brás, Parí Belém, Moóca and Ipiranga along the river valleys, the lower parts of the city, which were difficult to urbanize due to frequent inundations. Regulating the meandering rivers began to generate new space but aggravated the problem.

These workers' housing areas of were in contrast to the purely residential districts of the coffee aristocracy areas of mixed use with precarious residential housing (*cortiços*) and industries (Rolnik, 2008). The year 1872 made town history and is referred to as the New Foundation of São Paulo because the predominant construction material of buildings changed from adobe to brick with Italian masons importing the technology, which also marked the beginning of the industrialization process of the building sector.

São Paulo soon received the nickname Brazil's Locomotive and became a magnet for investments and (im)migrants which led during the turn of the century to an accelerated urbanization process and the installation of infrastructures (electricity, trams, road network etc.). The first car-ride in São Paulo is dated back to the year 1889 and is an important moment in the history of the city since it would change soon the industrialization and transport policy of the city.

In 1891 the city's most famous boulevard, Paulista Avenue was inaugurated and became then a residential area for the mansions of the coffee aristocracy. In 1894 the engineer Joaquim Eugênio de Lima passed the building law for the avenue. Future constructions had to keep a distance of 10 meters from the street and on both sides "gardens and trees" had to be planted on both sides on a two meters wide strip. According to Rolnik (2008) such legislations guaranteed a better urban quality for a certain social stratum despite the immense pressure on the land that was permanently caused by the population growth.

Rolnik (2008) further notes that at that time, discriminating agreements for public investments, reformations and investments - mainly in the west vector of the city - were made with only the elite.

> "Private gardens also began to gain a new significance and a new place within the plot. The buildings unfastened themselves from the lateral borders of the plot, first on one side, where they became set back to allow for a small garden.

Fig. 3.5: Colonial village São Paulo in 1822 in the year of independence - vegetation is not presented in the city model (Ipiranga Museum, above) and Rows of houses, narrow streets and no urban vegetation in 1900, when the rails for the tram system were laid (below).

Later they distanced themselves from the boundaries, remaining isolated within the plot, surrounded by large gardens. It was the beginning of mansions framed by romantic and classical gardens. These transformations which occurred during the second half of the 19th century, when the county became richer as a result of exporting products like coffee and rubber, were significant changes in the way Brazilian cities were built at the end of the 19th and the beginning of the 20th century.

The homes of the wealthy had definitely unfastened themselves form the boundaries of the plot and were decorated with vast gardens, combining two colonial traditions of settlements: the rural tradition of farm manor isolated in large fields of vegetation blended with the tradition of the urban dwelling, transforming the distancing of the building from the boundaries of the plot and mainly, the setback in relation to the street line, into standard and synonymous with level of quality of urban living.

Also at this time streets and squares began to be treated as gardens, decorated with trees and ornamental flower beds. As expected the process of landscaping was highly successful and some of the oldest and more traditional colonial squares received plantings and landscaping, losing some of their peculiarities, as plazas, courtyards and yards."

The colonial square (or dry space), used as a marketplace, area of military and political manifestations, and of recreation, lost some of its functions, receiving urban trees and others new functions. The commercial and military uses were minimized, and it became an area devoted to the contemplation of nature and relaxation – uses formerly reserved to the garden (Robba and Macedo, 2003).

The City Beautiful

During the second half of the 19th century the cultural influences arriving from France and England led to the rise of campaigns to render cities modern, sanitary, healthy and beautiful also in Brazil. At the time of the *Sanitary Movement* in São Paulo significant renovations were undertaken to transform the colonial city into a republican city. Interestingly the city beautiful approach promoted the planting of urban trees which were seen as elements to improve the situation and to achieve the aims of urban sanitation, health and beauty.

It was during this transitional period between the colonial urban model and a new kind of city – beautiful, healthy, and picturesque – that a new urban typology appeared: the landscaped square. The landscaped square would combine the two former traditions of the square and the garden (...) According to Segawa (1996, p. 49, cited by Robba and Macedo, 2003) in Brazil the garden was before this an antithesis to the (dry) square.

But according to Morais and Sevchenko (1998, p. 23 also cited by Robba and Macedo, 2003) the process of urban remodeling driven by health policies was also used as an excuse to expel the poorer social layers (often the former slaves) of the population who happened to occupy the downtown areas. The authors see in these cleanups the dissemination of the slums and the beginning of urban sprawl in São Paulo.

A similar process had already occurred in Paris with the implementation of

the Haussmann's boulevards and in Rio de Janeiro with the implementation of the *Avenida Central*. In São Paulo the foundation of the central quarter of *Higienópolis* (literally Hygienic City) in 1890 marks on one hand the desire for city beautification, health and sanitation, but also paradox *biopolitics* which included racial aspects leading to social exclusion and gentrification (Silva 2005).

Fig. 3.6: Streets and avenues (like Avenida Angélica in wealthy districts like Higienóloplis ca. 1880) received some landscaping, becoming lined with tress mostly exotic species usually planted at a distance of 5 meteres, note that street trees were recently planted and cast small shadows at noon (Robba and Macedo, 2003, p. 25)

"It is precisely at this moment that the squares in the most important cities became objects of landscaping projects. Squares could no longer have the characteristics of colonial plazas, lacking, vegetation or the picturesque elements of the Belle Époque

During the first decades of the 20th century, the model of the landscaped square became a paradigm of quality for open spaces, and even the oldest and traditional squares underwent some process of landscaping and gardening [...] Urbanistic landscaped projects like Praça Ramos de Azevedo and the Parque Anhangabaú in the Center of São Paulo were landscaped in 1911." (Robba and Macedo, 2003).

In terms of a *landscaping style*, elements and aesthetics of these projects Robba and Macedo report mostly European influences and the absence of an own Brazilian *landscaping style* (which developed only later with the modern movement) during this first period of urban landscaping:

"Brazilian landscaping architecture of the time was called Eclecticism.[10] This series, which involves gardens of the end of the 18th century up to the landscaped squares built in the first decades of the 20th century, is characterized by the appropriation of several styles and influences.

The violence and speed of these transformations grounded Eclecticism as the most expressive landscaping prototype in the country. For years, until the 1950s, the eclectic projects, even the late ones, were proposed and built, and its influence may be seen until the end of the 20th century.

Of course, the growing appreciation of the use of plantings in the city, so as to reduce the effects of intense urbanization in the great capitals, strengthened, throughout this century the typology of the landscaped square (Robba and Macedo, 2003).

3.1.2 Verticalisation versus Sprawl (1915-1929)

Today with the traffic chaos of sprawling[11] megacities it has become clear, why compact, densely populated structures promote short ways and combined with well-developed public transport sustainability. On the other hand opening up spaces for the integration of at (least small) green areas is considered important to achieve sustainability and *Qualified Density.*

Although more actual than ever the challenges of high population density, space-efficient land-use, mobility and environmental quality - were (and are still) discussed by the conflicting schools of though which follow the two most important urban planning theories of the twentieth century: Ebenezer Howard's clean but sprawling *The Garden City of Tomorrow* (1898) and Le Corbusier's theories of highly dense and verticalized modern cities (e.g. manifested in The *Radiant City*, first exhibited in Brussels in 1930).

Both European-born modern urban planning theories were imported, discussed and subsequently implemented in adapted forms and at different scales in São Paulo. This marked a moment of decision making for urban policies and design for the forthcoming period of most rapid metropolitan growth, although it would become clear only later, that unplanned sprawl would override both theories. This chapter looks deeper into this important moment of the cities' (and the global) history which is worth being observed more detailed and critically because it implies the fundamental contradictions and planning decisions.

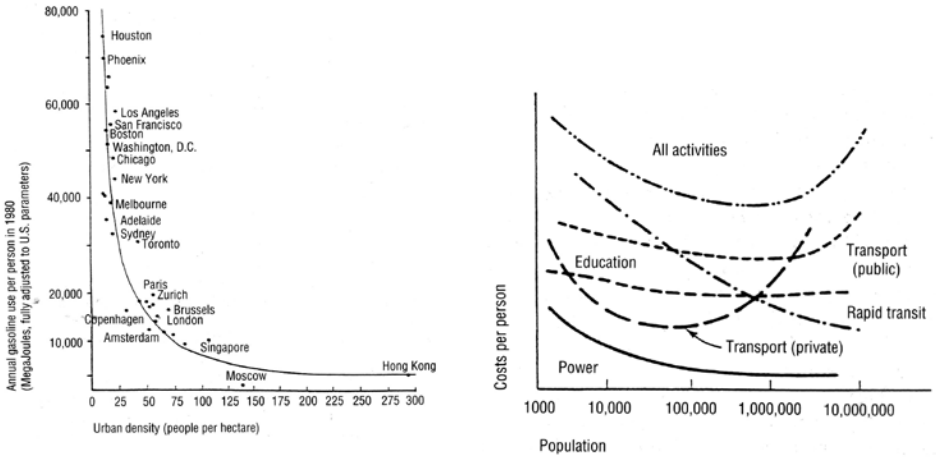


***Fig. 3.7:** Relations between urban spatial extension, density, mobility, gasoline consumption and cost (thus efficiency and sustainability)*

Technically the enormous and exaggerated urban growth of São Paulo became only possible with the enthusiastic welcoming of the new and modern construction methods and materials and the industrialization of the construction. They would paradoxically allow São Paulo's urban areas to spread widely into the surrounding natural landscape trivializing and overriding the urban planning theories.

Although related, the concepts created competing schools of thought, with conflicting opinions on the spatial relations between open/ green spaces, building heights, population densities and consequently distances. Retrospectively these contradictions were revised by Jane Jacobs in her 1961 book *The Death and Life of great American Cities*, judging both principles as "nothing but lies" and as "divorced from reality".

The Garden Neighbourhoods of São Paulo (1915-1930)

During the 19th century the European agglomerations of London and Paris had already experienced the ecological consequences of the new industries and the interconnected rapid urban population growth. In England, the "First Pollution Report" had been published already in 1819/1820. In the same year

[10] Its name was inspired by the architectural prototype of that time and remains an important pot-pouire "style" in many so-called neoclassical and postmodern building examples in São Paulo.
[11] The planning term of "urban sprawl" refers to urbanized areas, which develop in the course of the mostly uncontrolled expansion of settlement clusters like living, work etc.

the first important study on urban climate (after Roman Marcus Vitruvius pioneering work) was published by Luke Howard in London. The year 1858 became the year of *The Great Stink* due to pollution of the river Thames.

However, Ebenezer Howard (1850-1929) had looked at the living conditions of the poor in the late-nineteenth century in London. The most important idea of Howard which has influences until today was probably the (re-)approximation and integration of the built and the natural environments and a socio-environmental equilibration (Ottani and Szmrecsányi, 1997).

Howard managed to build the two prototype *Garden Cities*, Letchworth and Welwyn, located North of London. Both were designed by architect Barry Parker and built from 1903 on. Subsequently the concept was exported and enthusiastically adopted, especially in the Americas.

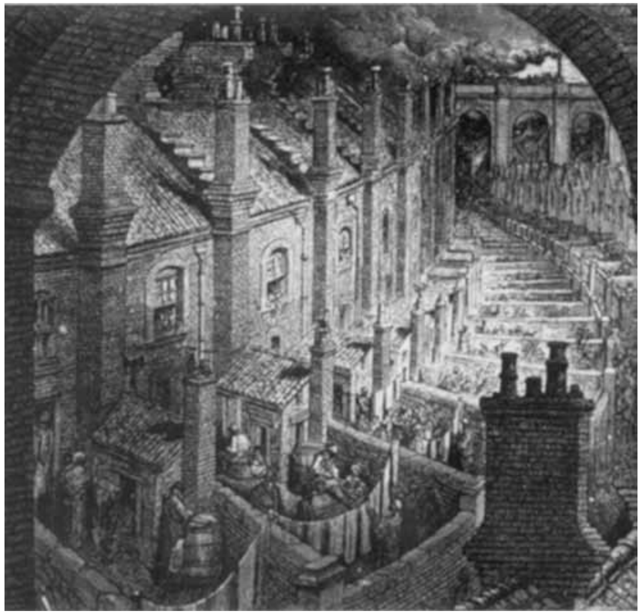
In Brazil the *Garden City*, was the most innovative model at the time, was first applied at neighbourhood scale and later at a larger scale in the state capitals of Belo Horizonte (Minas Gerais) and Goiânia (Goias). All neighbourhood projects emerged from the drawing board and were implemented in São Paulo, Rio de Janeiro and Recife. In São Paulo eight *Garden Neighborhoods* were built from 1912 on by the British company *City of São Paulo Improvements and Freehold Land Company Limited* (City CIA.) which had bought 12 million square meters of development land in São Paulo.

The *Garden Neighbourhoods* implemented in São Paulo by the *City CIA* were: Jardim América in 1915, Anhangabaú in 1917, Butantã in 1918, Alta da Lapa/ Bela Aliança in 1921, Pacembú and Alto de Pinheiros in 1925, later Jardim Guedala in 1949 and City Boaçava in 1950.

São Paulo's *Garden Neighbourhoods* (much smaller than the self-sustaining satellite or dormitory Garden Cities in England), were spatial expansions of the city of São Paulo into the Western and South-Western directions (see Levi-Strauss, 1952 p. 112), adding rather a green sickle than a complete *Green Belt* to the city.

São Paulo's first *Garden Neighborhood, Jardim America*, was also developed by the architect Barry Parker who had designed the Garden Cities in Great Britain with Howard between 1917 and 1919. Parker adjusted the original concept - which had (according to Feldman, 2005) already suffered an adaptation to the automobile through North-American engineers when it reached Brazil - further to the habits of the São Paulo coffee aristocracy clientele (Ferreira and Wolff, 2001). Apparently somewhere on the way Howard's original socio-environmental preoccupation with the Garden City got lost.

Due to the common practice of clear-cutting sites, all vegetation was removed before the



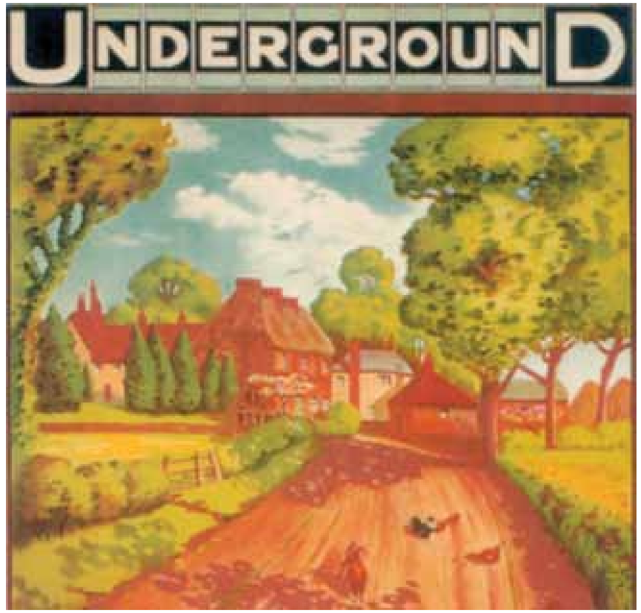


Fig. 3.8: Living conditions of the poor in the late-nineteenth century in London (by Gustave Doré, 1872) (above) and London Underground advertisement for access to green picturesque, scenic or even idyllic "urbanism" (below)

land division and beginning of construction of the *Garden Neighbourhoods*. Subsequently exotic (non-Brazilian) vegetation was planted, introducing a Second, *civilized, urban Nature*.

The *Garden Neighborhoods* of São Paulo had in the drawings of their building lots areas assigned to the establishment of squares of scenic and contemplative character. The well-landscaped but not densely populated urban structures of the Garden Neighbourhoods are also seen as the beginning of the urban sprawl and their results can be observed in so many suburbs, especially in the Americas, but also in Europe (Jacobs, 1961). Such urban-rural structures are considered unsustainable today because they are globally invading natural landscapes, causing enormous land consumption, provoking decentralized organization and long ways which is inefficient in terms of energy use for mobility (see fig 3.7).

According to Jacobs (1961) Ebenezer Howard proposed his “city-destroying ideas” because he hated “the wrongs and mistakes of the city thought it an outright evil and an affront to nature”. He “wrote off the intricate, many faceted cultural life of the metropolis” and proposed decentralist *Green Belt* Towns instead, with “factories hidden behind a screen of trees”, regionally distributed throughout large territories.

Meanwhile, according to Robba and Macedo (2003), in Brazil the urban centers began to expand quickly in the 1920s, due to the implementation of the industrial production model and the growing commercial activity. The socio-economical transformations attracted large population masses in search of jobs leading (besides immigration) also to large national rural-urban migration (*rural exodus*).

In São Paulo of the price of the urban land under the system of absolute property (*Lei das Terras*, 1850) rose with the expansion due to the fact that the demand was larger than the supply. Aside from the regular market which fostered real estate speculation, deforestation continued a form of demarcation of property and appropriation of land.

> “Open spaces, especially the informal ones like meadows, fields and the outskirts were taken up by buildings. In this phase, the open space, public and urban, became one of the options for existing areas of leisure in the city. Parks and public squares began to be used for this purpose, even though devoted exclusively to contemplative activities”.

> “The growing density of the city led to a subsequent diminishing of the amount of open (green) spaces imbedded in the urban network, increasing the value of those remaining even more.” (Robba and Macedo, 2003).

Le Corbusier’s visit in São Paulo 1929

Rapid urban transformation and also preoccupations with modernism had already been discussed in São Paulo’s important *Semana da Arte Moderna* (Modern Art Week) in 1922 and the

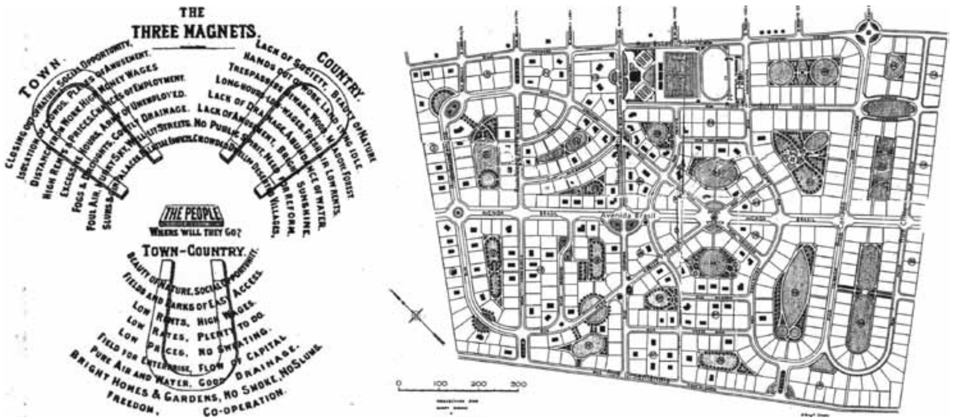


Fig. 3.9: The “Three Magnets Scheme” was emblematic for Howards projected antithesis of the chaotic megacity (left) and layout for the first Garden Neighbourhood implemented in São Paulo, Jardim America 1915 (right).

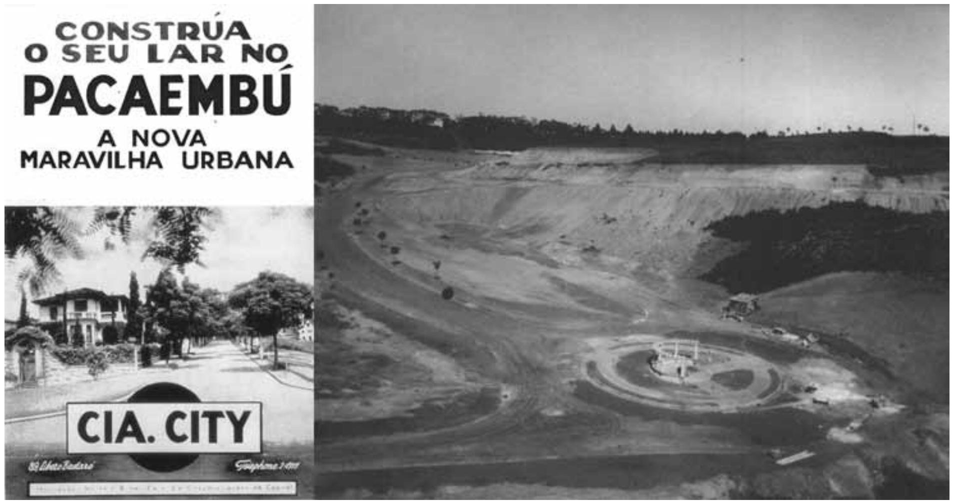


Fig. 3.10: Announcement for the “new urban miracle” of the Pacaembú Garden Neighbourhood by City CIA (left) and the clear-cut Tabula Rasa implementation scheme (right)

majority of the *Garden Neighbourhoods* of São Paulo had already been implemented when "the man with the most dramatic idea" (Jacobs, 1961), first visited Brazil, Argentina and Uruguay, countries eager to apply - and to transform - the European born modernism.

Although Le Corbusier did not construct his own work in Brazil[12], his approach and architectural ideas had an even more important influence on modern Brazilian architecture and urbanism than those of Ebenezer Howard two decades before. Le Corbusier pioneered modernism in architecture in Latin American and laid the foundations for Bauhaus (and/or the International Style[13]), seeking to improve living conditions through densification, considering urban environmental well-being through access to light, air and opening (see Behling, 1996, p. 156).

His 1920s dream cities „*La Ville Radieuse*" and "*La Ville Verte*" did not consist of low rise buildings, like the Garden Cities, but of "majestic skyscrapers", which were surrounded by parks, lawns[14] and expressways, achieving "an impressively high density" (Jacobs 1961) of 1000 inhabitants per hectare. "The whole city is a park", Le Corbusier declared.

According to Jabobs (1961) "yet ironically, the *Radiant City* came directly out of the *Garden City* and Le Corbusier accepted the *Garden City's* fundamental image". But he wrote: "The *Garden City* is a will-o' the wisp", "Nature melts under the invasion of roads and houses and the promised seclusion becomes a crowded settlement. The solution will be found in the *Vertical Garden City*" (Le Corbusier cited by Jacobs, pg. 32).

Important is to point out that in Le Corbusier's concepts the importance of urban vegetation was also recognized: In his statements on the travels to South America (published in 1930) he also reports in the chapter "Moscow atmosphere" about the socialistic planning of a "Green City" 30 kilometers outside of Moscow exclusively for "the recreation break of the city-dweller on the fifth day". Corbusier resumed: "You do not heal sick people, you create healthy people".

For Le Corbusier the modern city was to "be replete of trees". "It is a need for the lungs, it is tenderness with regard to our hearts, it is the flavor of the great geometric plastic introduced in contemporary architecture by the iron and for the reinforced concrete" L.C. wrote (1930, p. 156).

However, his model certainly laid the bases for the phenomenon of High-Rise Sprawl, which later, as a consequence, became typical for São Paulo. This High-Rise Sprawl can also be observed today also in other American city centers, but also especially in cities situated in tropical emerging countries like Malaysia, Hong Kong, Singapore etc.

Le Corbusier did not foresee the danger that Nature in future building practice would also melt under the maximum exploitation of lots due to real estate speculation (in terms of building volume and footprint), resulting in minimum distance spaces (or green, open spaces respectively). With the development of *Gated Communities* in Brazil and the fencing of the real estate property, the public space would be reduced further to street/ sidewalk corridors.

Le Corbusier's diagnosis for São Paulo when he visited the city in September 1929 was already "city center illness" and "traffic problems". As a solution he proposed to solve the problem by imbedding two "gigantic viaducts" (see fig. 3.13), a cross meeting in a right angle represented horizontal connections an aqueduct-like infrastructure of continuous residential buildings with highways on top, into the surrounding hills. Its cruciform shape was intended to give the city an armature that would order its future development. "It's not a fly-over, it is a roll-over", he wrote (Le Corbusier, 1930).

Interestingly and much in contrast to contemporary theories of Le Corbusier's idea to revitalize the already degraded downtown was proposing *the death of the traditional street, overpasses* and

Fig. 3.11: São Paulo's Central region with Park Dom Pedro II, the city's first high-rise Martinelli building, sparse of street trees (above) and meandering Pinheiros River west of city center (below) in 1929

[12] Except - according to Niemeyer - from the MEC in Rio, (see Fig. 3.17.) which is based on his drafts
[13] The tendency of an emerging "International Style" had been observed (and declared as a concept) by Philip Johnson and Henry-Russel Hitchcock already in the 1932. Hence according to this concept marks a tendency in which architecture would no longer be culturally and climatically adapted to its surrounding and the same typology would be constructed everywhere.
[14] Le Corbusier actually proposed mainly open spaces with lawns ("grass, grass, grass" as Jacobs puts it) and few trees (see Fig. 3.12.) and thus littler overhead shade (see chapter 6.2.1) in the public parks around the buildings, probably in order to maintain the views on the "majestic skyscrapers"

the *disconnection of urban functions* which influenced cities worldwide and later especially the layout of the new Brazilian capital Brasília by Lúcio Costa in the 1950s.

Shortly after Le Corbusier's visit, in 1935, the another visitor, French anthropologist Claude Levi-Strauss described the degraded center of São Paulo on one of his first excursions, to Brazil approving Le Corbusier's observations:

> "Some mischievous spirit has defined America as a country which has moved from barbarism to decadence without enjoying any intermediary phase of civilization. The formula could be more correctly applied to the towns of the New World, which pass from freshness to decay, without even simply being old." (Levi-Strauss, written in 1935 but not published before 1952)

Fig. 3.12: La Ville Radieuse – or the "Radiant City[15]"was a prototype Tabula Rasa Plan Voisin for the central region of Paris 1930 (left) and La Ville Verte with vegetation covered open space (right) both projects published by Le Corbusier at the same time.

Modern Construction methods

The main reason for the modernization of the concept and the possibility to built vertical, dense urban structures was also a result of technological advance since Ebenezer Howard's proposals: The innovative and soon common application of frame construction, elevators, curtain walls and air conditioning in construction engineering changed construction methods allowing the verticalisation processes of cities. This also changed the relation the building and the ground-floor, und thus the relations of public and private spaces.

Fig. 3.13: Le Corbusier's 1929 vision sketch for São Paulo which implemented a traffic cross as a backbone into the hilly landscape (left) and the first modern, then avant-garde, "Casa modernista" in São Paulo by Gregori Warchavchik, 1930 (right)

[15] It is not clear whether "Radiant" might also refer also to highly reflective/ albedo building surfaces (see 4.3.1)

Le Corbusier visited São Paulo in same the year in which the first high-rise, the neo-classic *Martinelli Building* (see fig. 3.11), still with ornamental façades, was completed in São Paulo's center which also coincident with the moment that the city's population transgressed the one-million-inhabitants borderline.

While the Garden City can be described as a horizontal expansion causing enormous land consumption[16] Le Corbusier proposed verticalisation and densification to decrease land-use. Especially the then new material of reinforced concrete became the predominant construction material from 1930 on in São Paulo, displacing brick construction and allowing verticalisation (and thus density) through frame construction. This new industrial material further allowed the development of the typically modern Brazilian free-form organic style, e.g. shell structures, presented in the works of many Brazilian architects, especially that of Oscar Niemeyer, intending, according to his own words, "to imitate natural forms" (like the mountains of Rio as Le Corbusier said, see A I).

While climatisation was applied for centuries in the temperate climates through heating, the upcoming new cooling technologies became another success story in the hot climates. They changed (according to *Medela et. al.* 2007) the "habits of consumption and life style of the Brazilians" when it entered the market from the beginning of the century on. The first air conditioning in Brazil had been installed already between 1905-1909 in Rio de Janeiro's municipal theatre.

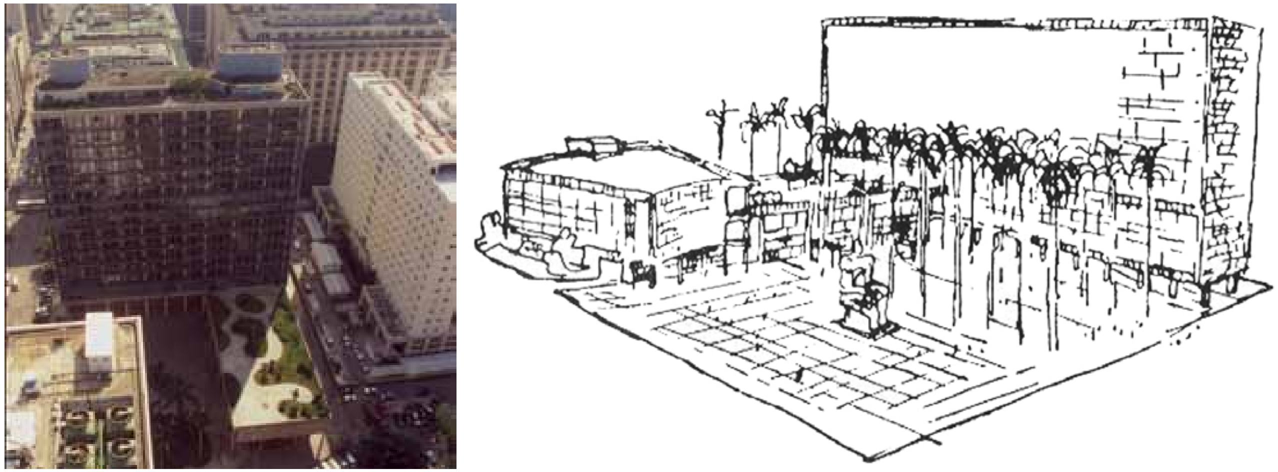


Fig. 3.14: Ministry of Education and Health (MEC) with Burle Marx's first roof gardens. Developed and constructed between 1936 and 1943 by Costa, Niemeyer, Reidy and others (left) based on ideas and sketches by Le Corbusier (right)

The first CIAM[17] congress had been held a year before Corbusier's first trip to Latin America (Behling, 1996 p. 129). Even though it marks the beginning of the *International Style* Le Corbusier's global approach still included (tropical) climate adaptations of buildings (so-called passive cooling elements today), for example *Brise Soleil* and *Roof Gardens*[18] which made part of Le Corbusier's "Five points of architecture"[19] and were first fully applied on the *Ministry of Education and Health* (MEC) in Brazil's then capital Rio de Janeiro, for which he acted as a consultant (see fig. 3.14.).

Interestingly, and as a counter-example to the high density urban developments proposed by Le Corbusier, North-American architect Frank Lloyd Wright proposed anti-urban (or suburban) development for the *New World* already at that same time. His concept named "Broadacre City" followed the Garden City´s ideology of "Back to Nature" (Behling 1996). Wright presented the idea in his article *The Disappearing City* in 1932. This concept can be perceived as a blueprint of contemporary so called *Eco-settlements* (see fig. 3.15).

In *São* Paulo the *coffee boom* - and thus the importance of agriculture in the São Paulo region – came to end with the saturation of the global market by 10th of October 1929. With the so-called *Black Friday* at the New York stock-market a global economical crises began which led to a period of permanent changes and a reorientation of the markets in São Paulo.

In terms of population density and extension of the urban area density the compactness of the city had decreased significantly during this period (not at least due to the *Garden Neighbourhood* development). In 1914 the size of the urban area was 3.760 hectares and the population density was 110 inhabitants per hectare, in 1930 the inhabited area had been multiplied by four, while the population density had decreased to 47 inhabitants per hectare (Rolik, 2008).

3.1.3 Metropolization (1930-2009)

"What is growth?"

"The growth of nature (and of children) is unusually perceived as beautiful and healthy. Industrial growth, on the other hand, has been called into question by environmentalists and others concerned about the rapacious use of

[16] In German also e.g. called "Landfrass" – Urban areas spilling into ("eating up") the surrounding natural landscapes
[17] Congrès Internationaux d'Architecture Moderne
[18] Seeking for an integration between city and landscape
[19] Le Corbusier in Vers une architecture

resources and the disintegration of culture and environment. Urban and industrial growth is often referred to as a cancer, a thing that grows for its own sake and not for the sake of the organism it inhabits (or as Edward Abbey puts it "Growth for growth's sake is a cancerous madness.")

But unquestionably there are things we all want to grow and things we don't want to grow. We wish to grow education and not ignorance, health and not sickness, prosperity and not destitution, clean water and not poisoned water. We (all) wish to improve (our) quality of life." (McDonough and Braungart, 2002)

This chapter describes the rapid and uncontrolled urban growth in the São Paulo region during the second half of the 20th Century, in which the modern urbanistic principles developed in Le Corbusier's theories e.g. International

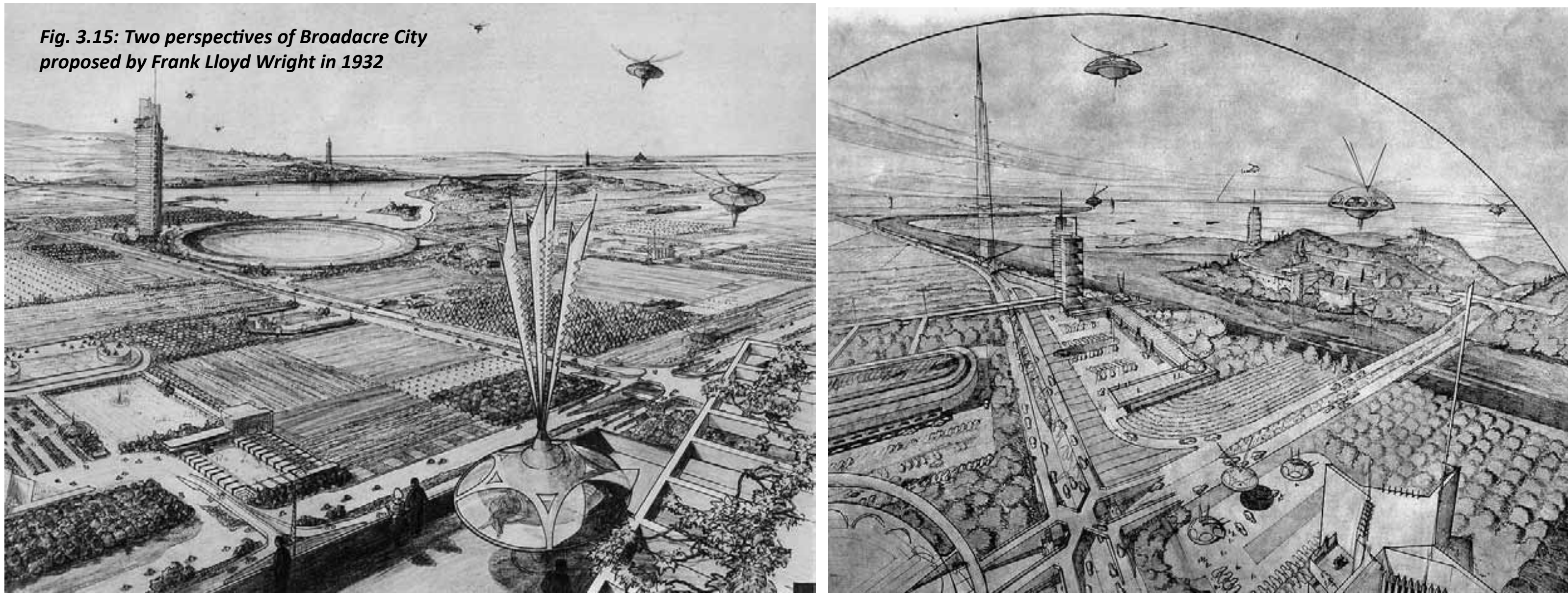


Fig. 3.15: Two perspectives of Broadacre City proposed by Frank Lloyd Wright in 1932

Fig. 3.16: Massive land use and landscape changes: Native Atlantic Forest (left) and the urbanized environment of the City Center (right)

Style, the car-orientated city etc. were applied. While these principles established cosmopolitan life in the *formal city* of São Paulo on one side, the *informal city* - were the urban theories failed - began to sprawl on the other.

This description also mentions the foreshadowing of the problems to come with the massive changes, as an underbelly of the rapid urban growth: sprawl, the success stories of the typologies which fostered built contrast and indirectly surveillance, segregation and violence, like *Shopping Centers*, *Gated Communities* (see *City of Walls*) and lead to *High-Rise Sprawl* on one hand and *Favela Sprawl* on the other, due to modified relations between the public and private space, leaving public spaces to degradation turning them *non-places* (see Augé 1994 and chapter 2.4)

Here the functions (like shelter, security, privacy and climate control) of the building envelopes - as an interface between inside and outside – the public and the private play an important (and even energetic and climatic) role, which lead to the actual discussion of a (sometimes cruel) competition for urban settlement space which has rarely left over sufficient green space.

During the decades after the *coffee boom* São Paulo's accelerated urban development took mainly place due to the industrialization progress of the region, (mainly car industry) with the city absorbing more immigrants from around the world, as well as due to the *rural exodus* (rural-urban migration processes mainly from less developed North-East of Brazil) triggered by the search for work, success or sometimes even survival.

The national migration was caused by poor profit opportunities in the countryside, the failure of an even distribution of land (agricultural reform) and the automation of agriculture. The wide belief in technical progress especially forced in cities, the better job opportunities, a promised break-out of static traditions offer a projection screen for desires and hopes (pull-factors), which makes it for many worthwhile to abandon a more calm rural life and to move towards stressful cities (Bodemann, 2002).

Unfortunately the cities, among them São Paulo, did not have robust economies capable of supporting more and more people, so that the dreams of many did not become true in many cases, leading to urban marginality and misery, often worse and more violent than observed in rural regions.

In 1932 the rapidly developing state of São Paulo even declared an independence war to the rest of the country, which failed after a short civil war. During the *coffee boom* an extended railway system had been established by British firms, which allowed rapid (and clean) urban locomotion since cars were still rare. It consisted of an inner-city tram system (see Fig. 3.5) , as well as train lines connecting the city with the state's hinterland and allowed maintaining a dense urban structure and reduced land-use for infrastructure.

This changed rapidly with Prestes Maia's radio-concentric Avenues Plan[20] which seemed efficient in terms of transport for a city of medium scale (and is not in terms of landuse). The future was thought to be individual road transport and not collective on rails which was also reflected in the deactivation of the rail system, as well as the stabilization of a system relaying on diesel busses. This model was later also applied on a national scale.

The most important local road traffic axes proposed by Maia were soon defined by major Fabio Prada (1934), preparing the circulation of petrol-driven vehicles, instead of electric trams, trains and trolleybuses, stimulating the local automobile industry which began to established along the river valleys: Ford had opened a factory in 1919, General Motors Brazil opened in 1925. At that time, horn and engine sounds were becoming part of São Paulo's daily life and cars gained increasing importance for urban policies and development until today.

As in the past preferring the interest of the elite in the development of the

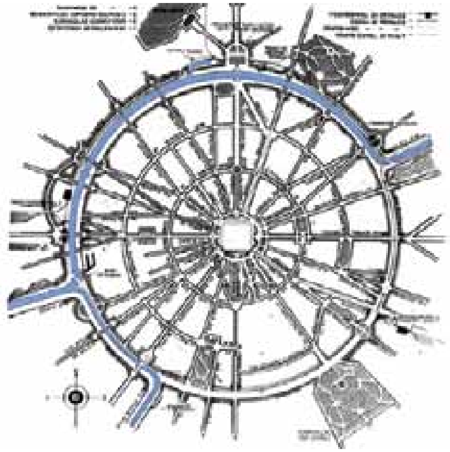


Fig. 3.17: The urban extension in the 1940s, the dense city still surrounded by forests and wetlands (above) and Prestes Maia radio-concentric Avenues plan 1929 (left)

[20] The Prestes Maia master plan stipulated the deviation and canalization of São Paulo's urban rivers

urban network took place following the South-West-Development indicated by the *Garden Neighbourhood* development two decades before. Levi-Strauss (1952, p. 122) had also observed these "mysterious strengths that drive so many cities westward, abandoning their eastern districts to misery and decay" already in the 1930s.

During the following period of urban development the CBD (Central Business District) of the city was constantly shifting, following the South-West vector, from the Old center (until 1950) via Avenida Paulista (1950-1960) to Avenida Faria Lima (1970) and on to Avenida Berrini (1970-1990) and Marginal Pinheiros (1990-2000) (see Meyer *et. al.* 2004).

According to Hehl (2008) at this time the formation of public areas was purely neglected because the inadequate infrastructure was regarded to be the more urgent problem. This nation-wide policy called *Rodoviarismo* (road construction and car-orientated development) was especially driven nationwide by the Getúlio Vargas administrations (1930–1945 and 1950–1954).

As a counter-balance São Paulo's now second largest but most popular and iconic Ibirapuera Park was created between 1951 and 1954 by Oscar Niemeyer, Roberto Burle Marx, Ulhôa Calvacanti, Zenon Lotufo, Eduardo Knesse de Mello and Ícaro de Castro Mello[21]. It became a living museum or *Gesamtkunstwerk*[22] consisting of integrated free-form modern Brazilian landscape planning and architecture and is today an important reference for the democratization of a two-tier society in the public space (see also 5.3.2). During the same time (1951-55) Niemeyer's, iconic wavelike *Copan Housing Union* (a *machine for living*) which mixes commercial, social and middle class housing, was constructed in the city center.

In 1950 São Paulo overcame the capital of Rio de Janeiro in terms of inhabitants. The city was absorbing enormous amounts migrants especially from the North-East of Brazil. While growth rates and horizontal expansion were increasing (see preceding chapter) the paradox and continuous process downtown degradation and urban sprawl became difficult to avoid. Later, besides from the aforementioned *High-Rise Sprawl* and the retreat of privileged into *Gated Communities* the dream of the homestead[23] (often with small gardens) contributed to the spatial expansion.

> "The settling throughout the 20th Century, of the urban model of production caused the population migration from the country to the city which together with the national socio-economic situation during the last decades, led to a phenomenon typical of the so-called developing countries: the existence of great metropolitan centers, swollen and over-populated, that centralize a great part of the production, opportunities, investments and financial resources and that in turn, attract more and more people in search of jobs." (Robba and Macedo, 2003).

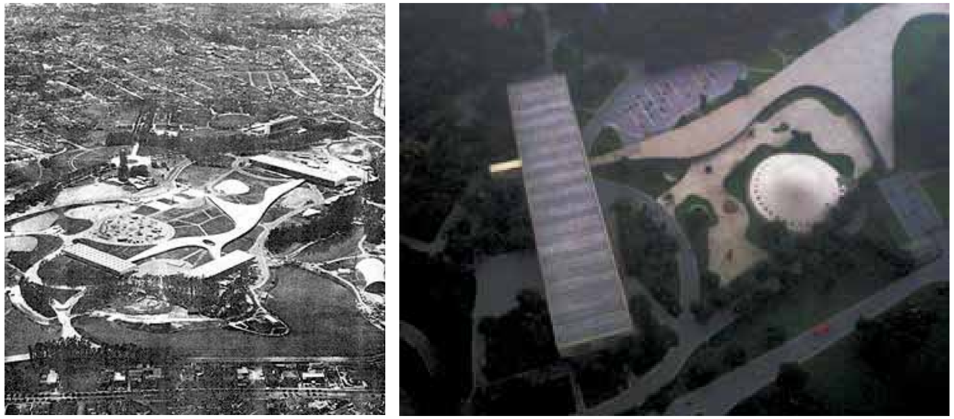


Fig. 3.18: Ibirapuera Park implemented between 1951 and 1954

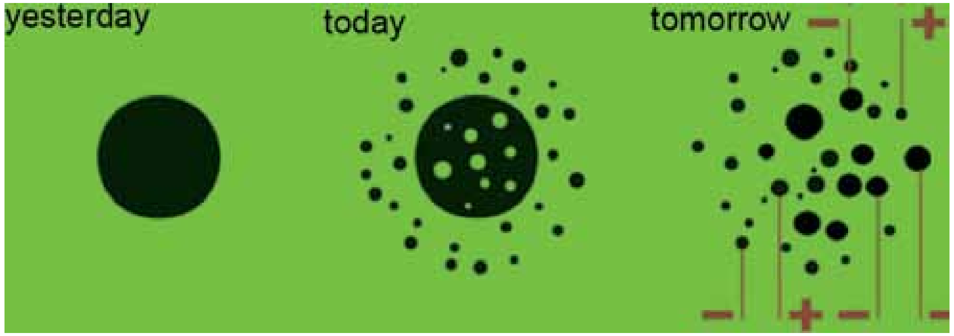


Fig. 3.19: Development of Urban Sprawl and fragmentation during the city's history

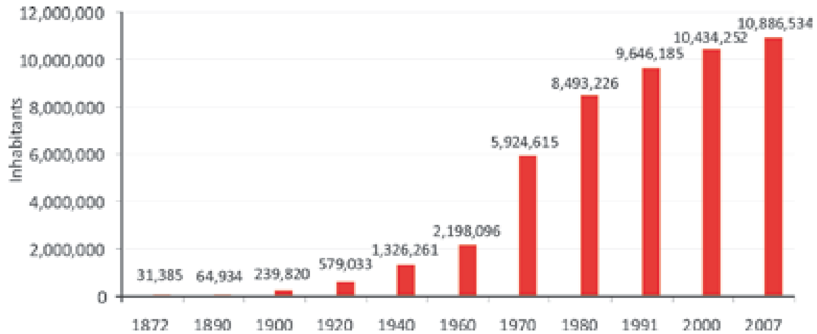


Fig.3.20: Dynamic population growth in the municipal area of São Paulo (IBGE 2007)

21 Ibirapuera in Guarani-Tupi language means "foul wood" because the region where the park is located was originally wetland. Before implanting the park the soil was dried out by strategically planting Eucalyptus trees
22 May be translated to "complete artwork"
23 In Portuguese: Casa própria, in German Eigenheim

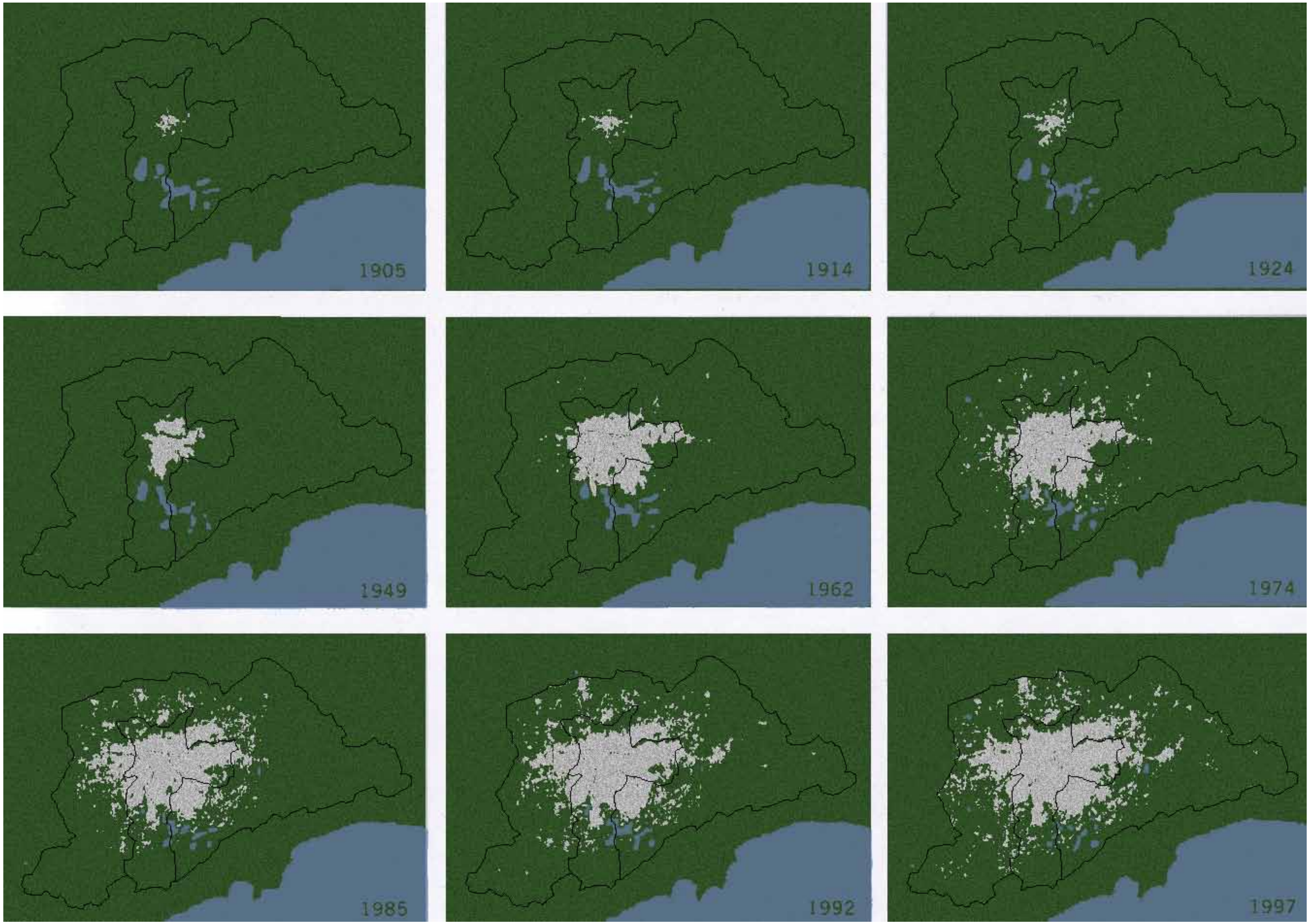


Fig. 3.21: Urban Explosion I - Growth of the urban area between 1905 and 1997, with massive sprawl from the 1970s on, and no clear line between countryside and city

Separation of Private and Public and Segregation

> "More lightly dressed as usually, I stroll over the waved meanders of white and black mosaic and perceive a special atmosphere in these narrow, shady alleys, which cross the main street; the transition between houses and street is less manifested than in Europe here; despite luxury of the merchandise displayed in the shop windows, the outlays of the stores stretch as far as on the streets so that one hardly notices whether one is outdoors or indoors. Because the streets are not only there to pass through; they are places to stay.
>
> Lively and peacefully at the same time, more animated but more protected than ours, they seduce me to make a comparison: the change of the hemisphere, the continent and the climate caused hardly anything different until now than making redundant that thin glass blanket, that creates similar conditions in Europe in artificial way: Rio seems reconstruct the Milan *Gallerias*, the *Galerij*, in Amsterdam, the *Passage des Panormas*, or the hall of the railway station, to Saint-Lazare under open skies". (Levi-Strauss in Rio de Janeiro 1934, published in 1952)

After the period, of the early modernism, in which the Brazilian society had tied to absorb and mix the multi-cultural influences the social climate began to change in the 1960s, which coincident with increasing growth of the *favelas* and the continuous growth of the social gap.

The widely unplanned and construction of buildings and infrastructure of the *car-orientated city* led to an increasing maldistribution of urban open and green spaces and started to change many traditional relations and boundaries and to socio-environmental conflicts.

This development changed the relation between inside and outside, public and private space, sharpening the separation of classes and the triumphant advance of the typologies of *shopping centers* and *gated communities* with residential towers (*High-rise sprawl*), but on the other the growth of the *favelas*.

The emergence of the typologies of *Shopping Centers* (in English *Shopping Malls*) and gated high-rise communities in São Paulo a tendency of increasing restrictions of public access to certain areas. Caldeira's 1992 book *City of Walls* by treats these segregation phenomena in São Paulo in detail.

Ironically the emergence of artificial environments occurred during the time when visionary architect Richard Buckminster-Fullers (1895-1983), preoccupied with energy consumption, urban growth and climate control proposed his biomorph project of the *Geodesic Dome City* (1968) during the *space age.* Under a gigantic dome stretching over Mid-Manhattan he pretended to create an all-year spring climate (through natural means), a cleaner and safer, simply utopian city, which is an approach that inspires *Shopping Malls* and *Centers* - as they are *cities within cities* (Behling, 1996, Spangenberg, 2004).

However, the roots of the shopping centers lie, according to Padhilha (2006), in the cold and temperate climates of Canada and the United States but became soon a success story world-wide, due to the

Fig. 3.22: Naturally ventilated "Shopping Center Grandes Galerias" in the center of São Paulo (left) and aerial view of Shopping Center Ibirapuera, a Sub-Center in South of the city (right)

aforementioned comfortable indoor climate, which stimulates the human being, to feel well and to consume while the "resistance is eroded" (Koolhaas, 2001). *Shopping Centers* were inspired by the market halls in Paris, London and Milan, although they are intimately linked with the *American Way of Life* (Padhilha, 2006).

> "Urban private space that disguises as public, example for what anthropology designed as *Non-places* discriminate not only because they offer what the poor cannot buy but because their existence is supported by a symbolic that eliminates those who do not know how to decode its signs." (Padhilha ,2006)

> "Sound, scent, light, air, even plants are manipulated to extract the desired response from consumers (…) nature now serves the most artificial process, (...) operating as one of the primary mediums to lure the consumer (…). Nature is now a *replascape* (…) using the aura of the naturally familiar to disguise the mechanics of the synthetically composed. (...) Part real, part synthetic". (Koolhaas, 2001)

The development of the new centralities (sub-centers) often generated by shopping centers also often lead to degradation of the surrounding commerce and the surrounding environment: It was found that areas around shopping centers are 2ºC hotter due to anthropogenic heat (see Soares, 2007)

Shopping Centers further have the following properties:

- Pedestrian paths are separated from (road) traffic and allow save strolling
- Restricted access either due to control mechanisms or due to shame of (potential) users who feel not appropriate to enter or cannot read the signs (semi-public spaces).
- Controlled indoor spaces, that suggest an effect of safety which makes one feel being *part of something special*
- All-year controlled air temperature (Enclosed Mall Air Conditioned *Emac,* see Padhilha, 2006)
- Generous *decór* with plants, trees, seating arrangements, fountains and sculptures.

The first *Shopping Centers* and *Gated Communities* opened in Brazil at the same time and in São Paulo: *Alphaville Gated Community* in 1965 and *Iguatemí Shopping Center* in 1966. The development generated new centralities (partly in traditional neighbourhoods as well as in the peripheries) leading to increasing multi-centrality (thus sprawl) being triggered by mobility and triggering more locomotion.

Degradation of public spaces

The new development fostered the further degradation of public spaces: broad avenues (cutting former neighbourhood context into two), flux-dynamic fly-overs (like later the undesired *Minhocão*[24]), as well as inundated tunnels started to confound the population with ever decreasing the environmental quality of the public space.

> "Urban gardens are open spaces fundamental for the improvement of environmental quality for they allow for a better air circulation, insulation and drainage, besides serving as scenic references in the city. They should not, however be called squares because they do not hold social programs, as leisure and recreational activities, and in many cases because they are not accessible to pedestrians due to its situation next to big, well traveled roads[25]. "(Robba and Macedo, 2003, p.17)

The urbanization processes and population growth continued in the peripheries, in the core districts were the infrastructure is well-developed, shrinking population numbers can be observed (SVMA, 2000). Following the security measures of the new philosophy, even green spaces can be notified as parts of restricted spaces in Brazil, for example fencing and closure of most public parks at night ("gated public green") for security reasons (Carrasco, 2007)

> "Brazil has many squares.[26] Very few, however, resemble the celebrated medieval and Renaissance European squares. Only a few colonial spaces, which have survived until today, display such a morphological structure, for instance *Largo do Pelourinho* in Salvador, *Patio de São Pedro* in Recife, and *Patio de Colégio* in São Paulo." (Robba and Macedo, 2003)

Gated Communities and the Real Estate Market

While *Shopping Centers* can be perceived as semi-public places, *Gated Communities* (which range in Brazil between the small size of so-called *Vilas* and whole cities) tend to separate completely from their surroundings by using fences and/ or walls, transforming more and more urban space into restricted areas.

As São Paulo based urban planner Cãndido Malta said[27]: the consolidation and compaction processes are often eroded the initial sales arguments put forward by construction firms for real estate enterprises. These arguments are e.g. elevated views on the urban landscape, being surrounded by vast green space (or even pristine forest), calm streets etc. Malta left clear that the green, the views and the promised seclusion and calmness of the street later vanishes with (pretended sustainable) densification processes and when the individual car traffic increases.

During the urban consolidation processes of verticalized urban fabrics further enter in conflict with horizon views. This concept becomes readable in names of releases of recent real estate enterprises like *Open View* (observed in Pinheiros, 2008) *Horizontes de Brooklyn*[28] (observed in Brooklyn, 2007) Generally the sales rule is, the more elevated an apartment (the better the horizon view) the higher its value.

> "In the 1970s, cities like Rio de Janeiro and especially São Paulo became great metropolitan centers, absorbing enormous population masses. The exaggerated growth of these cities forced the reconstruction and the enlargement of the urban infrastructure, especially that which related to transportation, housing and leisure. (…) The role of the open urban space in these large cities or metropolitan centers is constantly being ratified by the exaggerated urban growth; from the point of view of urban environmental quality its existence is fundamental." (Robba and Macedo, 2003)

Public Transport

Late, but finally in the 1970s subway lines began to be constructed in São Paulo to mitigate increasing transport problems. The lines were following the radio-centric corridor lines intended by Le Corbusier and Prestes Maia in the late 1920s partly substituting the radial expressways. Simultaneously the grid plan *PUB* (*Plano Urbanístico Báscico*, 1968) was introduced to reinforce the road network.

In the neighboring city of Curitíba (at a distance of ca. 350 km and then governed continuously by architect Jamie Lerner 1971-1975, 1979-1983 and 1989-1992) slowly sustainable urban change become visible achieving the best development pattern in terms of quality of urbanization. The city waged with an efficient guidance plan and successive technical municipal administrations the appreciation of "green" to raise the level of quality of life of its inhabitants.

[24] Portuguese: Earth Worm
[25] E.g. so-callled traffic islands which are often not pedestrian refuge islands but non-places
[26] São Paulo ca. 4000, according to RSVP 2006 - ano2 nº24
[27] In a personal interview in 2005
[28] Literally Horizons of Brooklyn

I'm convinced that every city in the world, no matter of scale, no matter the financial resources, can have a significant change in less than two years. (...) With environmental issues you can make important changes (...) It all depends on the city, but anything is possible. It's not a question of scale. Sometimes mayors use as an excuse that their cities are too big. But no, it's not a question of scale; it's a question of philosophy. (Jaime Lerner, 2004)

The politics of transforming Curitiba into the "ecological capital" of the country was a strategy by the government to promote and make the local administration known in the 1980s. In the process of fostering and valuing "green" the city gained a series of open spaces, old spares were renovated and some new build. (Robba and Macedo, 2002).

Another South-American city, the city of Bogotá also underwent similar processes increasing both green and public transport BRT[29] infrastructure under prefect Enrique Peñalosa (1998-2001).

Pioneering cities which put environmental issues on top of their agenda emerged from the late 1960s on and especially in Germany important work was carried out towards *urban ecology*. In the City of São Paulo also an increasing environmental sensibility became notable with the creation its Departamento de Parques e Áreas Verdes (*Depave - Department of Parks and Green Areas*) in the 1970s, which was later turned into the SVMA (Secretary of Environment and Green Spaces) later (Robba and Macedo, 2003).

"The need to preserve the remaining environmental legacies and the serious problems of metropolitan areas – like floods, landslides, high atmospheric pollution and contamination of waterways – which began to show as a consequence of the process of urbanization without planning, also fostered, in the 1980s, the rise of the ecological consciousness." (Robba and Macedo, 2003).

Concerning the more common design strategies and policies of contemporary horizontal public and green spaces were also interpreted by Robba and Macedo (2003).

"In some cases, the project would make the informal appropriation of the public space official, that is, squares occupied by open markets and peddlers. Some authors proposed peddlers´ pavilions and buildings designed to shelter markets and grocery stores.

The design of projects known as contemporary move freely between geometric outlines, graphics, rigid elements and the most irreverent post modern forms, passing through proposals which value the project scenically. Freedom is the best word to define this budding line of project. Bold designs, geometric, scenic, colorful, graphic, organic, evocative, celebrating forms from the past or old icons are being accepted and proposed, besides the introduction of elements and equipment of various kinds and forms, as colourful gateways, columns, ruins and sculptures.

The great visibility of urban public spaces and its importance within the city transform parks and squares in objects of political dissemination and propaganda. Sound policies concerning the creation and maintenance of public spaces in the city have a very positive effect in the approval of the administration by public opinion" Robba and Macedo (2003).

Fig. 3.23: The virginia creeper on the largest greened modern facade (by Gelpi & Gelpi, 1951) in the center of São Paulo (Rua Major Quedinho No. 273) was planted in 1983 by the lawyer Dr. Joaquim (Information provided kindly by facility manager Maluf Volpe). The building proposes a possibility of exploitation of urban space for plants

One of the recent changes within the urban fabric is the abandoning huge of inner-city industrial areas. These often contaminated brown-fields bear an interesting potential for protection of environmental heritage and new constructions paired with re-naturalization.

The actual state of the recently abandoned urban fragments (which evidence natural re-naturalization processes *within* the city) through spontaneous vegetation is well-documented in the *Guide to the Wastelands of São Paulo* (Almarecegui, 2006).

Aside from that the increasing sprawl and irregular settlements São Paulo have turned the city into a *Diffuse City,* in which mainly road-based car and bus transportation cause high degree inefficiency and unsustainability, which attracts urban researchers from around the world.

In 2002 the City approved a *Strategical Master* Plan (*Plano Diretor Estratégico)* which covers on one hand questions of conservation of green spaces and forests, interconections of sub-centers and

[29] Bus Rapid Transit

population density, but is on the other still very limited, especially in terms of environmental compensation.

> "The picture outlined at the end of the century in some capitals showed great metropolitan areas totally conurbated. Accommodating vast masses of people and facing a series of urban problems. The increasing volume of traffic of both vehicles and people, escalating violence, the progressive deterioration of the urban ecosystem and quality of life in the city, not to mention the difficulty in the management of such large urban complexes, are some of the problems bearing down upon our larger cities" (Robba and Macedo, 2003).

In environmental terms the urbanization has caused another unforeseen phenomenon called *Urban Heat Island* which is undesired in predominantly hot regions because it creates a apparently vicious circles between energy and water balance and consumption which will be discussed in the following chapter.

3.2 Socio-Environmental Conflicts Today

> "Like a huge, dynamic mass of gridded patches and structureless emulsions of masonry, asphalt, cars and people, the colossus sprawls across the endless plateau and gobbles its way through the dark green forest, leaving little reddish spots behind. The new developments and the mutations follow the logic of land speculation and are driven by instantaneous impulses such as a randomly placed new factory or an equally randomly placed favela. Admittedly, the ring of motorways around and through the centre, together with the railways and two rivers, form a bundle of infrastructure that allows us a distant panorama, and the built-up area occasionally follows an undulation of the landscape, but ultimately these nuances vanish amid the hugeness and chaos of the whole. Thus Sao Paulo has the appearance of a vast, monotonous, dense uplift cut across by deep clefts."
>
> "Every notion we may have about planning and architecture evaporates here. What do you do about cities with over 10 million inhabitants? What do you do about cities that threaten to swell into metropolises of 25 million inhabitants (São Paulo and Rio de Janeiro)? What do you do about cities that were planned for a few hundred thousand people but within a few decades have 2 to 3 million inhabitants? You cannot do them justice with 'normal' planning or 'normal' architecture. That would suggest that the contemplative slowness of the plan or design would work here. In Brazil, action is chronically overtaken by events. No time for consideration, no time for reflection. That's a European luxury, but here every municipal organization is powerless against the proliferation of the city. All that can be done is to keep things under control. Urban planning becomes a matter of policing rather than a political or cultural discipline." (Wim Nijenhuis and Nathalie de Vries/ MVRDV Architects, Rotterdam, in "Eating Brazil" 2000)

The sprawling *megacity* of São Paulo is today (2009) the largest Brazilian Megacity, the largest of the Americas and as well the largest of the southern hemisphere - and at the same time its youngest. It ranks between the 3rd and 5th largest agglomerations in the World[30]. São Paulo's metropolitan area houses almost 20 million inhabitants, distributed in an area of 1887 km² (1998). The *macrometropolis* of São Paulo (in a range of roughly 100km around the capital) includes various other municipalities which are important for the Brazilian economy.




Fig. 3.24: Illustrative resume of environmental problems: Urban energy balance leads to urban climate, thermal discomfort and elevated energy consumption, the urban water balance to inundations after torrential summer rainfalls caused by soil sealing in São Paulo, 2001

São Paulo's economy represents 31%[31] of the national Gross Domestic Product (GDP). The economic development however, has led on the other hand to significant degradations of the urban environment and quality of life (especially of the poor), (Municipal Environmental Agency SVMA, 2000, Jacobi, 2006), which is a common situation in many large cities in tropical developing countries.

São Paulo insular urban development covers only 0.01% of the Brazilian territory, all Brazilian cities sum up 2%, but 82% of the Brazilians live in these "hot spots", the cities, while their impacts on the global climate remain unknown. Almost a third of the population of the municipality of São Paulo (about 4 Million people) life in the *favelas*, often occupying "preserved areas" at the peripheries many located upstream from drinking sources (water

[30] http://www.un.org/esa/population/publications/wup2001/WUP2001report.htm
[31] http://www.emplasa.sp.gov.br/portalemplasa/infometropolitana/rmsp/rmsp_dados.asp <access on 26th of June 2009>

protection areas) in the South of the megalopolis sprawling into what should have been the "green belt" of the city.

Like many megacities São Paulo acts like a magnet which attracts (pulls) large push population masses and also shocks an sbschrecken and pull factors

São Paulo has become city of great contrasts and inequalities. The richest 10% of the population hold the half of the income of the municipality while the poorest 20% gain only 2% of the total (Veiga, 2007). Further in Brazil the urban-rural decline is significant (which has led and leads to rural exodus).

In societies like the Brazilian, the quality of the constructed environment is a stigma of social exclusion. Being poor normally signifies to not have access to a constructed environment of quality. The rich inhabit areas of environmental quality which is much better than those inhabited by the poor, the *favelas* (in Instituto Socioambiental, 2008 p. 392)

The environmental impacts of urbanization in threshold and developing countries located in tropical latitudes are mainly regional, due to the combination of accelerated and unequal processes of urbanization (without proper urban planning), environmental vulnerability and economical instability. In contrast the impacts of human settlements in the developed countries do have nowadays rather global impacts, principally due to excessive consumption of energy for heating and artificial illumination purposes (based on Goldemberg, 1995).

The environmental impacts of the urbanization in the tropics become most apparent observing the megacity of São Paulo facing massive environmental problems complicating a future sustainable urban development (Bodemann, 2002). To a large extent these problems are caused by the urban sprawl, thus transportation needs and the inadequacy of the existing urban structure.

According to Jacobi (2006) São Paulo's contemporary environmental problems - subdivided into the topics air, water, soil, waste, loss of biodiversity and local climate change (partly linked to the loss of vegetation cover) - lead to negative impacts on the population and the populations quality of life but to different degrees (see chapter 2.3). São Paulo's environmental challenges are resumed comprehensively in PNUMA/ SVMA, IPTs (2004) "Report GEO City São Paulo: panorama of the environment" (see chapter 2)

3.2.1 Tropical Urban Climate

Especially urban climate is an undesired environmental change in predominantly hot climates. It is a symptom directly or indirectly linked to all aforementioned issues will be outlined shortly here. Comparing the city to a metabolism the urban heat island can be compared to a "fever" (Soares 2007), a symptom, not necessarily an "illness" which results from an ongoing process of soil sealing and deforestation for infrastructure needs and settlement areas.

The urbanization process has led to changes of the urban energy and water balance, which results in harsher impacts in tropical latitudes due to higher solar radiation income (Akabari *et. al.* 2001) and torrential rainfalls. As a result of its rapid urbanization process São Paulo suffers today from an increasing number of severe inundations and modified near surface climates.

This chapter treats the phenomenon of the urban climate in predominantly hot cities like São Paulo. Worldwide massive land-use change, (here the transformations of dense forests into cities through deforestation and subsequently soil sealing through construction led to and local, regional and global climate changes, which remain to be estimated. In contrast to cities located in the temperate climate regions the urban heat island is undesired in cities located in predominantly hot climates because they increase thermal stress and elevate energy expenses for air conditioning.

Brandt (2006) analyzed the urban climate of the city of Bochum/ Germany (latitude N 51º, temperate climate) applying the *willingness to pay method* and found that benefits of urban climate for citizens in cities of the temperate climate, may overweight its costs. The advantages of urban climate are according to Brandt's survey (less fog, snow and ice, consequently less costs for winter services, decreased heating costs, interestingly more warm nights summer for outdoor activities like barbeque etc.).

The main causes for the urban heat island and its intensity are: latitude, topography, land-use, water bodies, vegetation ratio, size and infrastructure, anthropogenic heat, air pollution, urban structure (h/w ratio) and population density. The latter shows a contradiction between apparently sustainable high population density due to small footprint and elevated ambient temperatures (see 3.2.1).

Urban heat island(s) are isothermal patterns or patchworks and local climatic impacts principally linked to land-use, construction materials, vegetation degree etc. Especially in the tropical cities the *surface heat island* occurs due little overhead shade and due to dark (low albedo) surfaces (such as asphalt and bitumen roofs). These hot surfaces lead to increased ambient air temperatures through convection and thus the *heat island*, which is especially dominant after sunset (Bruse, 1998).

Heat Island and Summer Oasis

Due to the increased sensible heat fluxes emitted by conventional heat absorbing and storing construction materials some areas in the city overheat more than other regions. Especially low-rise districts with large *sky view factors* (SVF) sparse of vegetation shade tend to develop *heat islands* on calm sunny days, retaining and emitting the absorbed energy until late at night (hot, dry, desert climate).

In contrast the more comfortable *summer oasis* climate develops close to water bodies, forests, parks, as well as in *Garden Neighbourhoods* through shade and evaporating (relatively cool ground and leaf) surfaces (Akbari *et. al.* 1988) (cool, humid, forest climate). The evaporation *summer oasis* effect of vegetated areas depends on *evaporation* of humid soils associated to vegetation and on *evapotranspiration* through the plant metabolism (see chapter 4.1.4).

Dry soils, which are common in urban areas due to sealing of the ground, evapotranspiration cooling will might be limited (Oke, 1987) and in tropical cities also to the high vapor saturation of the air (in very sultry climatic situations).

Although the difference of ambient temperature of heat - oasis island effects at city-scale may be as significant as 10-12 Degrees Celsius between rural surroundings and city core of a megacity like São Paulo (see Lombardo 1985, Soares, 2007 and Kuttler, 2004), regionally (at neighbourhood scale) the differences in cities usually do not exceed temperature differences between 1 and 5 ºC between a park and a region sparse of trees (McPherson and Simpson 1995). The sizes and density of canopy islands and the distances between them seem to play an important role.

Scales	Boundaries	Range	Min	Max	Author
Citywide	Rural-center	ca. 15 km	10.00	12.00	Lombardo 2007
District	Neighborhood with high/ low GWR	ca. 1500 m	0.09	2.14	Velasco 2007
Neighborhood	Square-Canyon-Park (8 hectare)	ca. 250 m	0.30	3.60	Spangenberg 2007
Single Tree	Below - outside tree canopy	ca. 5m	0.31	1.17	Abreu 2008

Table 3.1.: Measurements of maximum temperature differences - heat island intensity – (in ºC) between green areas and urban areas in São Paulo which usually occur during late afternoon, early evening

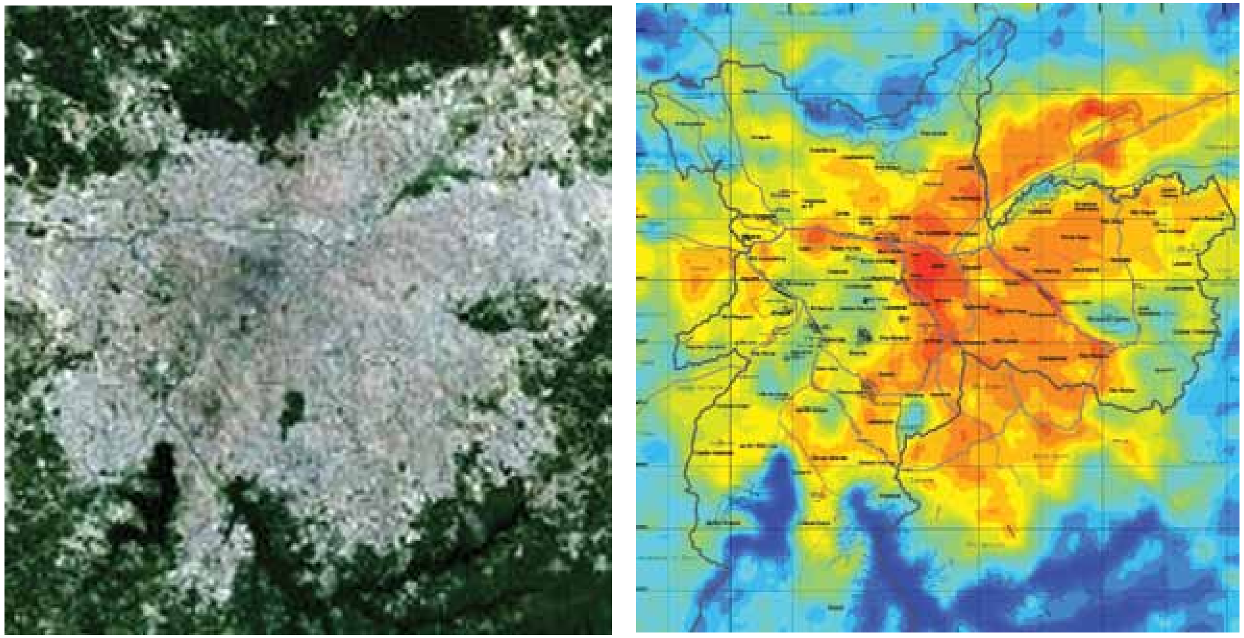


Fig. 3.25: Land-use (left) and the Urban Surface Heat Island as a result of urban/ rural land use Image obtained through remote sensing, thermal mapper TM5+ Landsat 7 ETM+ 03.09.1999 at 9:57h with a spatial resolution of 30x30 meters (SVMA, 2000).

The Environmental Atlas of São Paulo (SVMA, 2000) includes a map (based on remote sensing data) showing surface temperatures in the city of São Paulo (Urban Surface Heat Island). The lowest surface temperatures were found in parks and consolidated districts located in the south-west of the old downtown, which, are often well landscaped and green (e.g. *Garden Neighbourhoods*). The highest temperatures were found in the west the center in low rise regions, sparse of vegetation, (e.g. Brás, working men's cottages) and along the former industrial valley of the Tamanduateí valley.

In some cases good exposition to winds and verticalisation (and thus low sky view factors, like in the region of Paulista Avenue) can also generate oases climate, but remain extremely hot during summer midday hours, see chapter 7.1.1).

According to Ali-Toudert (2005), the climatic effectiveness of the vegetation within an urban structure depends on the ratio green area/built-up area, as well as on the size, location and own characteristics of the plant (species, density, shape, size, volume, age, etc.). The benefits of the vegetation increase with the increase of its proportions (Saito et al. 1990, Avissar 1996).

According to Ali-Toudert (2005) the cooling effects (e.g. air temperature decrease) of large parks were found to extend in the surroundings at a radius of several hundred meters and can even lead to breezes. However, these effects become insignificant for small vegetated areas (Shashua and Hoffman 2000). Hence, it has been suggested that several smaller areas with sufficient intervals are more cooling effective than one large green space (Honjo and Takakura 1990, McPherson 1992, McPherson et al. 1994b).

Shashua-Bar and Hoffman (2000) investigated the cooling effects of shade trees at small urban green sites, courtyards and streets in a subtropical location (Tel Aviv, Israel, N 32º). They found for several planted urban streets that the cooling effect is about 1 K and up to 3 K at the hottest hour of the day. The highest effects are registered at the centre of the canyon at mid-distance from the edges but the cooling effect decreases noticeably when moving to street edges.

Anthropogenic Heat

A mentioned before heat emissions of machines (like air conditioning equipment, cars etc) and crowds of people pollute the thermal environment and lead besides from land-use etc. to the formation of urban heat islands.

For example Krusche *et. al.* (1982, p. 57) report that local air temperatures in autocades can be elevated by 2°C in Germany and Lombardo (1985) mentions commercial districts like the shopping area of Rua 13 de Maio in São Paulo's center show elevated ambient temperatures due to metabolite (anthropogenic) heat.

The following overview resumes that the overall sensations caused by the urban climate during the summer season in low latitudes are mainly negative, but tend to invert during the winter and can thus create positive sensations (like in the temperate climates, see Brandt 2007).

Regional Climate and Change

São Paulo was originally nick-named *Cidade da Garoa* (The City of Drizzle) and is thus considered a rather cool city by many Brazilians. Compared to other Brazilian cities, São Paulo's climate is more temperate, but by world standards it is actually warm.

> "The climate of São Paulo is (...) one of the most pleasant of the world, with all the attractions of a tropical climate without any displeasure of excessive heat. (...) The nature of the soil and of the climate offers inexhaustible sources of wealth" (Spix and Martius 1823)

> "São Paulo possesses the most temperate climate in the world" (Saint Hilaire 1940)

As an indicator for the atmospheric changes it became obvious that the climatic phenomenon of drizzle rarely occurs nowadays. According to geographer

Significant parcels	Value	Participation
Fuel of transport sector	5.16E+17	41%
All industrial sector	3.43E+17	27%
Human biomass	2.54E+17	20%
All public and commercial sector	6.32E+16	5%
Electric energy of residential sector	4.94E+16	4%
Gas for cooking of residential sector	3.27E+16	3%

Table 3.2: Conservative estimation of energy dissipated in the Metropolitan Region of São Paulo through human activities in 2000 (Azevedo, 2001b)

		Rural - Urban	Summer	Winter
Radiation	**Global Radiation**	-10%	☺	☹
	Albedo	strongly varying	☹	☹
	Reflected Long Wave Radiation	+10%	☹	☺
	Sunshine Duration	-10%	☺	☹
	Sensible Heat Flux	+50%	☹	☺
	Heat Storage (Soil & Buildings)	+40%	☹	☺
Temp	**Air Temperature** (Annual mean)	+2°C	☹	☺
	Particular Cases	+15°C	☹	☺
Wind	**Wind Speed**	- 20%	☹	☺
	Direction and squall	strongly varying	😐	☹
	Turbulence	strongly enhaced	☺	☹
Hum.	**Humidity**	More in summer, less in winter	☹	☹
	Precipitation	more (leeward)	☹	☹

Table 3.3: Overview of impacts and sensations of urban climate in hot cities (based on Hupfer and Kuttler 2004) Key of sensations: ☺ = increased comfort, 😐 = neutral, ☹ = decreased comfort

Lombardo (1985) the dew point has increased with the temperature (land-use change, urban climate) and has changed precipitation patterns.

São Paulo's *Urban Climate Map* (Tarifa and Rezende, 2001) reveals that the hottest natural climates developed along the river valleys (due to thermal inversions). Located on the *Tropic of Capricorn* (and thus in the marginal tropics) São Paulo's climate is according to *Köppen* Cw, warm-temperate, with winter-dry climate, with both continental and maritime influences. Due to its elevated situation on the Brazilian high plateau at a mean of 800m above sea level but only at a mean of 40km from the sea, the temperatures are lower than typical for the latitude (tropical altitude climate).

February has the highest average temperatures, with typical maxima of 27°C and minima of 19°C while the coolest month, July, has equivalents of 21°C and 12°C All-time record temperatures are 38°C and -2°C. Rainfall is abundant at 135cm, falling mostly in the warmer months.

The phenomenon of snowfall in the São Paulo region was rare, already in the past. The last snowfall event was registered on 25th of June 1918 with -3ºC air temperature. Rocks shaped by glaciers in the *Park Moutonneé* in Salto, North of São Paulo prove that glaciers covered the region during the last ice-age.

Although the seasons are not very distinct (but readable due some trees which lose their foliage at the end of the growing season) there are certain climatic characteristics of the two main seasons:

- São Paulo's hot & humid summers are usually long and (increasingly) hot. Summer rains (usually in the afternoon) are often torrential causing inundations, and the breakdown of the traffic system.
- Further the physical and thermal properties the typical materials of which cities are made of (see fig. 3.25) and the small fraction of green areas lead to elevated radiation and air temperatures and the undesired phenomenon of the urban heat island.
- During the arid winter (June to September) the daily climates vary, so that climate of all seasons can occur within the course one day, from very cold at night to very hot sensations at midday. Cold stress occurs mainly under the influence of polar air masses. Lower solar paths and deep, shaded and windy street canyons can intensify the sensation of cold stress, especially during the mornings and in the evenings. Since heating facilities are uncommon, indoor climates are also uncomfortable. Due to the absence of rainfalls, humidity drops sometimes below 10% while air quality decreases with humidity causing climatic situations which are (according to the World Health Organisation) dangerous to health.

Various studies (Lombardo, 1985, Gore, 2007) indicate, that the overlay of

- ***Global Heating*** (due to global CO_2 emissions)
- ***Tropical Climate*** (due to high latitude)
- ***Localisation in the marginal Tropics of the Southern Hemisphere*** (with higher summer CO_2 concentration in the atmosphere, due to less land mass and thus vegetation, see Al Gore, 2007[32])
- ***Urban Climate*** (due to land use, surface climatic response and anthropogenic heat waste)

results in increased climate change, and the tendency of local heating. Lovelock (2006) mentions that the urban development – due to the mentioned different mechanisms - may combined even trigger loops (or rollovers) leading to an accelerated local climate change.

In a *worst-case scenario*, based on estimates considering a continuous rise of

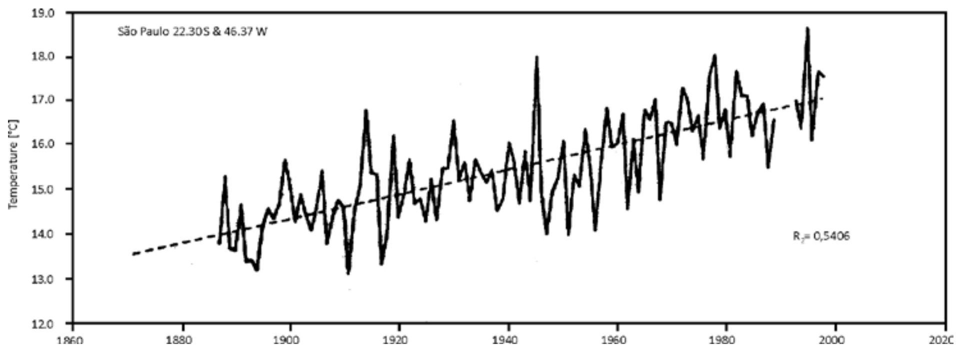


Fig. 3.26: Increase of winter air temperatures in São Paulo by Morengo and Rogers, 2001

global CO_2 levels assigned to increased air temperatures, Lovelock (2006) estimates that the situation in Brazil could become unbearable soon:

> "Concerning my estimates the situation will become unbearable around the year 2040. Most of the tropical areas, including the whole Brazilian territory, will practically be too hot and dry by then. In Latin America for instance, (climate) refugees will gather on the Andean mountain range and in other higher situated places. Up to 2100 it is probable, that around 80% of the humanity disappears". (James Lovelock in an Interview with Veja São Paulo, Edition 1979, 25. Oct. 2006)

A more *moderate (conservative) scenario* based on historical, local measurements was given by Morengo and Rogers (2001). According to the Brazilian climate researcher the São Paulo region the mean air temperatures will increase until 2050 by 0.9°C to 2.8°C, (simulated with the models DJF and JJA) and mean precipitations will as well increases by 9-13 percent, (simulated with the models MAM and SON). However, according to the author El Ninã could also change rain regimes and the region could become drier in the future. The IPCC report predicts an increase of ambient temperatures in the region of up to 2-4°C.

The differences of the results of the prognostics indicate the complexity of climate modelling. However, all studies indicate increasing air temperatures, considerable climate changes, either due to natural processes and/ or due to human activities, such as the urban development (see chapter 3.1.3). This leads to increased thermal stress, higher energy consumption for cooling, as well as increased water consumption during very hot periods.

[32] Al Gore (2007) "An Inconvenient Truth" Film

3.2.2 São Paulo's *Urban Forest*

An *urban forestry* is considered to be the "sustained planning, planting, and protection of trees residential tree lines and forests in urban areas" (Blouin and Comeau 1993). Broadly defined, urban forests, constitute all (public and private) vegetation (also non-tree, like creepers, bushes, green roofs etc.), within urban areas (Rowntree, 1986). The Anglophone concept of the *urban forest* is recently also being applied in Europe by Konijnendijk, 2000.

In literature urban vegetation is commonly referred to as an *urban forest* because most of the strategies and practices used for managing and maintaining urban vegetation initially came from and continue to be updated by foresters (Pedlowski, *et al.* 2002).

However, there is, according to Rowntree (1986) some skepticism about referring to the leaf mass of urban vegetation as an "urban forest" because there is the potential that the notion overstates the situation. Instead some people prefer the idea of an "*urban savanna*", which is especially true, in arid tropical megacities with sparse vegetation like São Paulo.

The original biome in the São Paulo region is that of the *Atlantic Forest* (in Portuguese *Mata Atlântica*), Tropical and subtropical forests, which stretch along Brazil's Atlantic Coast from the northern state of Rio Grande do Norte to the southern state of Rio Grande do Sul.

The forest structure of the *Atlantic Forest* contains multiple canopies that support an extremely rich vegetation mix of broadleaf evergreens, as well as semi-deciduous trees. Further it includes an astonishing diversity of ferns, mosses, climbers and epiphytes ("air plants" or plants that attach to other plants) including lianas, orchids and bromeliads. Altogether the forest boasts 20,000 plant species, many of them found nowhere else in the world, representing 8% of the Earth's plant species and a higher biodiversity that in the Amazon forest.

Due to the aforementioned pressure of urbanization processes along the coast, the remnant of the biome is estimated to be less than 10% of the original vegetation cover and is often broken into hilltop islands. Despite its diminished state the Atlantic Forest still ranks as a global conservation priority.

In the metropolitan region of São Paulo (which is one of the three largest urbanized and sealed regions in the world) the process of massive and continuous deforestation can be continued with the timeline of the urban-rural development and shows the outcome of the massive urban sprawl from the 1950s on.

Concerning the threshold density between urban forest and pristine jungle, it should be pointed out, that the concept of an *urban forest* separates density, structure, morphology and biodiversity from a pristine „jungle", since it is by definition cultivated - managed and maintained.

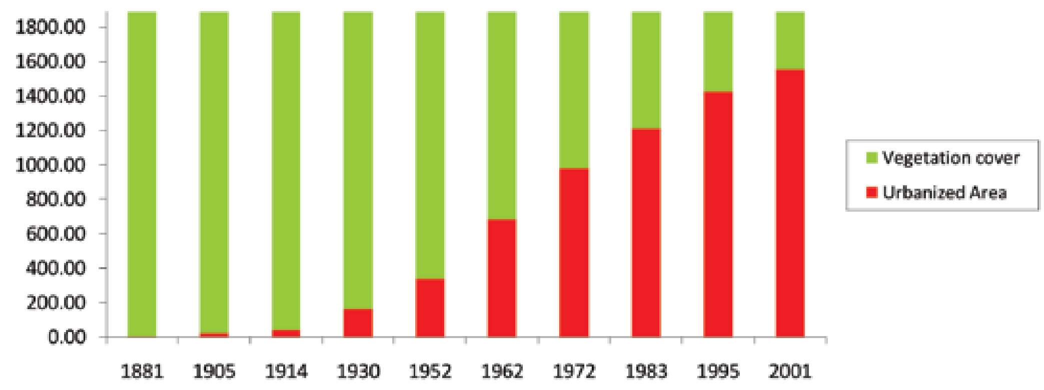


Fig. 3.27: Urban Explosion II (see also figures 3.18 and 3.19) - The metropolis' spatial development - literally emerging out of the forest: Spatial bare urban development versus an estimate of inner-urban city vegetation covered areas (within the urbanized area of ca. 1887 km² 1995). The graph shows a slowing of the deforestation process within the metropolitan area.

Within metropolitan area of São Paulo the *Atlantic Forest* biome, which once covered the whole hilly region except from swam regions of the rivers is rare. Some small fragments of the pristine forest remain for example in *Parque do Estado*, in the refuge of an Indian tribe in the Santo Amaro district and in the State University Campus (USP - Cidade Universitária) as well as at the peripheries, and especially on the northern (Serra da Cantareira) and in the southern boundary districts, near the barrages which supply the city with drinking water, were the urbanization is still proceeding in an accelerated manner.

The combined deforestation and urbanization processes have turned natural landscapes into artificial ones. In the peripheries literally hundreds of island settlements are scattered in the forest (and in already deforested regions). A clear line between the urban and rural does no longer exist (see figure 3.19), while on inner city brownfields spontaneous vegetation slowly reclaims the urban space (Almarecegui, 2006).

The process of urbanization further also lead to significant loss of (animal and plant) biodiversity due to loss of vegetation cover, which is fragmented and very unevenly distributed within the urban fabric. In many regions of the city urban land occupied by infrastructure and buildings

[33] based on handout by landscape architect Patricia Akinaga, GSE Harvard University Cantinho do Céu Workshop by Prof. Christian Werthmann in São Paulo, March 2nd 2009

reaches limits of intensity through widely unplanned development. This continuous pressure on land has rarely left over public spaces for recreation, causing serious environmental problems, such as floods, urban heat island with elevated surface and air temperatures (fig. 3.25).

The continuous deforestation process, even within the city was reported by *The Estado de São Paulo* reported in 2006: in 2005 of a total of 81.219 requests by citizens was made to the SVMA. Of those only 2.339 (2,8%) were for planting, while 44.024 (54,2%) were for pruning, and 11.423 (14%), for tree removal. Considering the additional vegetation cover loss in the sprawling peripheries in the north and the south of the municipal area (about 10% within one decade) the overall vegetation cover is still decreasing. According to the legislation planting is allowed without consulting the SMVA, pruning and felling designed environmental crime (Duran, 2006).

Principal street tree species

The favorable climatic conditions for plants allow a whole-year-growth-period for vegetation (high radiation and precipitation) and, even in the metropolitan area, a relatively high biodiversity of more than 300 (native and exotic) species of street trees is scattered throughout the city (Gregório, 2006). The majority of the urban forest is composed by dense, evergreen, broadleaf vegetation, but amongst the most typical street tree species are also

Fig. 3.28: Volumetric relation between construction materials and biomass in the municipality of São Paulo based on data analyzed by Almarecegui, 2006b "The Construction Materials of São Paulo" and Spangenberg (2008) for more details.

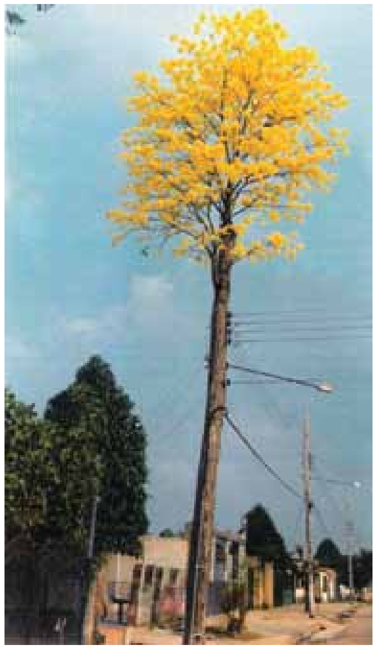


Fig. 3.29: Natures "violence"/ spontaneous vegetation: The tropical climate creates often better conditions for vegetation than for man shown illustrated here with: Ipê Tree re-tillered from a post which was made of it in Porto Velho/ Rodônia (left) and spontaneous green façade in Luz/ São Paulo (right).

some semi-deciduous species, which stay bare during the short, dry and at times also hot winter (May - August).

Today in the *urban forest* non-native species are common, as the mild climate and abundant rainfall permit a multitude of tropical, subtropical and temperate plants to be cultivated, with Exotic tree species like Tipuana (*Tipuana Tipu*) (Origin: Argentinian) and Eucalyptus *"paulistana"* (a natural hybrid between *E.globulus* and *E.robusta*, originally Australian) being especially ubiquitous.

The exotic Tipuanas planted decades ago in the center of the city (and the *Garden Neighbourhoods*) have adaption problems and are especially fragile to termite attacks (vermin) and thus sensitive to windbreak. Thus the urban green space planning office (SVMA) decided not to plant (and to indicate) certain exotic species like Tipuana and Ficus, due to windbreak and superficial roots and to focus on native species.

São Paulo's Urban Forest in Numbers

Although the urban green space planning office (SVMA) is starting to work on mapping and monitoring program (SIGAL) today highly reliable numbers or information on the composition of the urban forest structure (species) are not available. Some estimations[34] were published in Gregório, (2006) in the article *Beyond the grey, metropolis has much Green* (Além do cinza, metrópole tem muito VERDE)

The article includes for example an estimated number of trees on street and squares trees (which will be used for estimations in chapter 6.2.2.3) and includes information on the implementation plans for parks which's was (at the time of the publication) lower than the number of *Shopping Centers* (32 versus 47). In the following table data from other sources were added to the data given by Gregório, but it was found that the numbers (e.g. vegetation cover) vary considerably from other sources (see chapter 6.3)

Distribution of Green

The economic development of the city, has led on one hand to enormous richness but on the other hand to significant degradations of the urban environment and quality of life. As mentioned the distribution of street trees in the city is unequal, according to the SVMA (2000) reflecting the model of the concentration of landholding and income[35]. In some central and eastern districts, where only few isolated trees are encountered, the vegetation is negligible, while in the richer districts especially the *Garden Neighbourhoods* reasonable fractions of vegetation cover are maintained.

The distribution of the estimated 1.5 million public urban trees, scattered across the streets and squares (see also Journal da Tarde, 5th of July 2007), is of high interest, because especially these trees bring direct benefits (such as shade) to occupants (see chapter 6.2.1 and 7.1.1). According to

Popular Brazilian Name	Scientific Name	Family	Origen
Aroeira pimenteira	Schinus terebinthifolius	Anarcadiaceae	Native
Aroeira-salsa	Schinus molle	Anarcadiaceae	Native
Ipê-roxo-de-bola	Tabebuia impetiginosa	Bignoniaceae	Native
Ipê-roxo-de-bola	Tabebuia heptaphylla	Bignoniaceae	Native
Ipê-rosa	Tabebuia avellanedae	Bignoniaceae	Native
Ipê-amarelo-cascudo	Tabebuia chrysotricha	Bignoniaceae	Native
Ipê-amarelo	Tabebuia ochracea	Bignoniaceae	Native
Ipê-branco	Tabebuia roseo-alba	Bignoniaceae	Native
Espatódea	Spathodea campanulata	Bignoniaceae	Exotic
Jacarandá-mimoso	Jacaranda mimosaefolia	Bignoniaceae	Native
Urucum	Bixa orelana	Bixaceae	Native
Paineira-rosa	Chorisia speciosa	Bombacaceae	Native
Aldrago	Pterocarpus violaceus	Leguminosae	Native
Flamboyant	Delonix regia	Leguminosae	Exotic
Pau-brasil	Caesalpinia echinata	Leguminosae-Caesalpinoideae	Native
Pau-ferro	Caesalpinia ferrea var.leiostachya	Leguminosae-Caesalpinoideae	Native
Sibipiruna	Caesalpinia peltophoroides	Leguminosae-Caesalpinoideae	Native
Chuva -de-ouro	Cassia ferruginea	Leguminosae-Caesalpinoideae	Native
Falso-barbatimão	Cassia leptophylla	Leguminosae-Caesalpinoideae	Native
Alecrim-de-campinas	Holocalyx balansae	Leguminosae-Caesalpinoideae	Native
Farinha seca	Peltophorum dubium	Leguminosae-Caesalpinoideae	Native
Manduirana	Senna macranthera	Leguminosae-Caesalpinoideae	Native
Pau-cigarra	Senna multijuga	Leguminosae-Caesalpinoideae	Native
Bauinea	Bauhinia variegata	Leguminosae-Caesalpinoideae	Exotic
Tipuana	Tipuana tipu	Leguminosae-Faboideae	Native
Suinã	Erythrina falcata	Leguminosae-Papilionoideae	Native
Mulungu	Erythrina mulungu	Leguminosae-Papilionoideae	Native
Suinã-candelabro	Erythrina speciosa	Leguminosae-Papilionoideae	Native
Resedá	Lagerstroemia indica	Lythraceae	Exotic
Dedaleiro	Lafoensia pacari	Lythraceae	Native
Magnólia-amarela	Michelia champaca	Magnoliaceae	Exotic
Quaresmeira	Tibouchina granulosa	Melastomataceae	Native
Cinamomo	Melia azedarach	Meliaceae	Exotic
Uva-japonesa	Hovenia dulcis	Meliaceae	Exotic
Cedro-rosa	Cedrela fissilis	Meliaceae	Native
Ficus	Ficus benjamina	Moraceae	Exotic
Ligustro	Ligustrum lucidum	Oleaceae	Exotic
Pau-formiga	Triplaris brasiliana	Polygonaceae	Native
Salgueiro-chorão	Salix babylonica	Salicaceae	Exotic
Quereutéria	Koelreuteria paniculata	Sapindaceae	Exotic
TOTAL	40	14	Native: 29 Exotic: 11

Table 3.4: Principal tree species existing on the streets of the municipal area of São Paulo (in Geocidades report)

[34] According to a telephone interview with the author Erika Gregório on 20th of January 2009 the information was allocated by the Municipality.

SMVA (2000) 4.6m² is the mean green area per inhabitant in São Paulo is, much lower than, according to Perreira (2003) in Rio de Janeiro with 59,4 m², in Curitiba 55 m² and 120 m² per inhabitant in Brasília.

To get rough idea about how the trees are distributed in the city the following numbers give some indication: the neighbourhood of Lapa has 11 m², Moema 24 m², Tucuruvi 23 m², Vila Andrade 100 m², in Morumbi 239 m² per inhabitant. One of the areas with the lowest proportion of green per inhabitant is the central region of Sé with 0.21 m² per inhabitant. The region with the largest proportion of green cover is Engenheiro Marsilac in the very South of the municipality with 26.000 m² per inhabitant consisting mostly of *Atlantic Forest* fragments.

> "There seems to be some irony in the naming of the most established parts of the periphery "garden so and so." There are few places that are further from gardens than these places, whether in terms of the presence of greenery or green areas or in the sense of being esthetically pleasing. Quite the contrary, these areas are visually very unattractive. Buildings are covered in graffiti, garbage is thrown anywhere, and cars that were destroyed in accidents are left to rot on the side of the roads, giving a derelict feeling to the areas. There are no proper sidewalks, even on major roadways. This means that pedestrians have to compete with passing traffic on major roads, endangering their lives. Walking or waiting for a bus in such places is very unpleasant. The heavy smell of fumes from trucks and buses, and the noise from engines negotiating the steep hills all contribute to stress as do the lack of parks, playground, and green areas—amenities that make life a little easier". (Leonardo Shieh, 2006, p. 68[36])

Netzband *et. al.* (2006) have looked into the interconnection of the urban ecological parameters/ indicators such as vegetation cover, their social implications and vice versa in Santiago de Chile/ Chile. They found that the vegetation cover in cities is not only a natural phenomenon but also strongly influenced by socio-economic distributions and potentials and clearly linked to the income situation. A Brazilian study by Pedlowski, *et al.* (2002) shows the same tendencies in Campos dos Goytacazes in the state of Rio de Janeiro.

Environmental Inequity

> "The great contradictions of our time pass over the territory use." Milton Santos (Brazilian Geographer)

Although the distribution of urban trees (or vegetation canopy) can be considered as one (among many) indicators for quality of life, property value etc. it is important to point out that it is a difficult indicator because in São Paulo the amenities of vegetation cover are recognized as wealth (or even luxury) in inner city districts while in peripherical areas the forest vegetation cover is often considered an obstacle for expansion and land reclaim

Generally the unequal distribution *goods and bads* across the urban space reflect socio-environmental inequity (Köckler, 2007). According to Martínez Alier (2006) in Brazil Chico Mendes (1944-1988) was one of the first to defend environmental rights of the poor in Brazil; without following the typical discourse of environmentalists. Other important Brazilian personalities of the socio-environmental discourse were Jose Lutzemberger (1926-2002), Roberto Burle Marx (1909-1994) and Frans Krajcberg (born in 1926). Martínez Alier believes that "eco-justice is the response of the third world to the challenge of sustainability".

As suggested in the historical background, from the beginning of any urbanization processes deforestation attracts investments, because cleared areas (as well as yet forested) are perceived as exploitable or potential land for construction. Only recently the question whether "a standing forest is worth more than a felled forest"[37] which refers directly to the conflicts of territory and vegetation cover is discussed.

Although a general zoning is rough simplification (see fig. 3.31) in the real city, the Global City is in some cases found vis-à-vis the informal or illegal city respectively. Brazilian Geographer Milton Santos referred to the *Glocal City* since contrasts between rich and poor usually only found at great distances can be observed. These conflicts and violent fights for the urban space leads to urban developments stigmatized by concepts such as *gentrification* und *ghettoisation*.

According to Jacobi (2006) some of the environmental problems are directly linked to the loss of vegetation cover (like urban heat island, inundations, water and soil quality etc), while others (like transportation, waste etc.) could be improved by a broader vegetation but do not directly depended on the vegetation. These *viscous cycle problems*

Size of municipality	1,509 km²	SVMA 2000
Urbanized ares	870 km²	SVMA 2000
Number of Inhabitants	11,000,000	SVMA 2000
Trees per inhabitant	0.14	Calculated
Green Sace per inhabitant	4.6 m²	SVMA 2000
Vegetation Cover	21%	RSVP 2006 - ano2 nº24
Number of public urban trees	ca. 1,500.000	RSVP 2006 - ano2 nº24
Asphalted Road Network	11,916 km	PRODAM, 1997
Number of Squares	4,000	RSVP 2006 - ano2 nº24
Number of species	> 300	RSVP 2006 - ano2 nº24
Trees plantes per day	180	RSVP 2006 - ano2 nº24
Surviving	75-80%	RSVP 2006 - ano2 nº24
Workers	7,800	RSVP 2006 - ano2 nº24
Number of parks	32	RSVP 2006 - ano2 nº24
First: Parque da Luz	1,825	RSVP 2006 - ano2 nº24
Largest: Anhanguera	950,000,000 m²	RSVP 2006 - ano2 nº24
Second largest: Ibirapuera	1,600,000 m²	RSVP 2006 - ano2 nº24
Area of existing parks	15,534,197 m²	RSVP 2006 - ano2 nº24
New parks until 2008-09-21	39	RSVP 2006 - ano2 nº24
Urban Parks	19	RSVP 2006 - ano2 nº24
Linear Parks	22	RSVP 2006 - ano2 nº24
Annual Budget (2006)	106 Million Reais	RSVP 2006 - ano2 nº24

Table 3.5: São Paulo's Urban Forest in Numbers

[36] http://stellar.mit.edu/S/project/saopaulo/materials.html <access on 25th of June 2009>

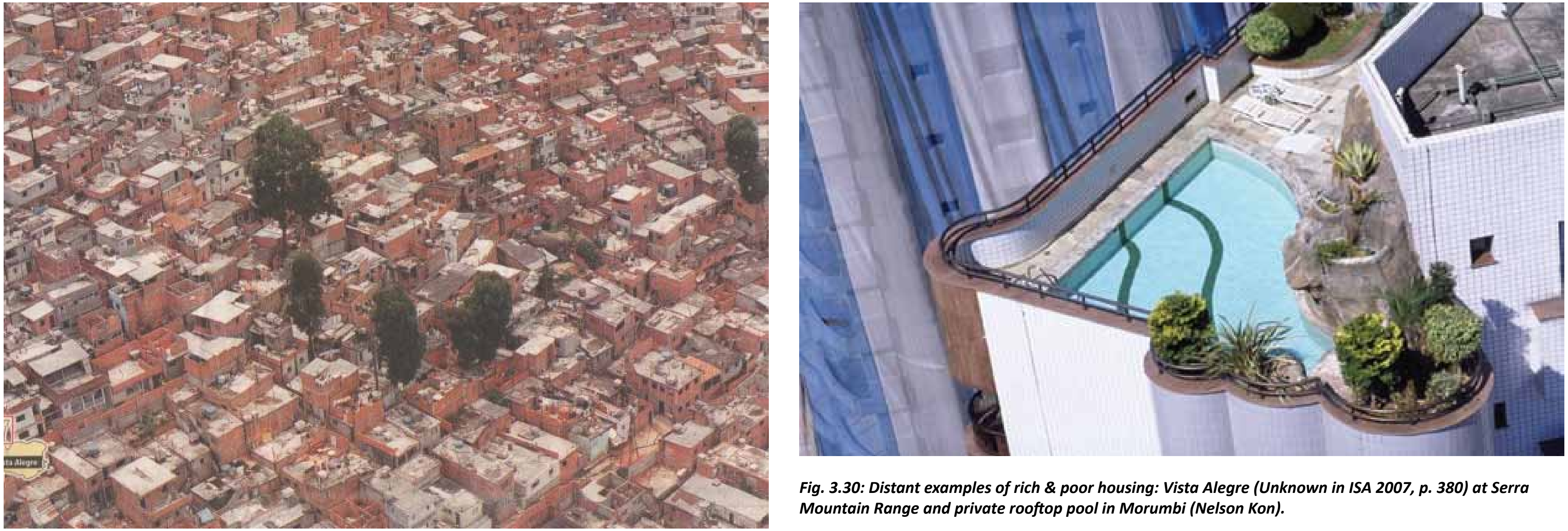


Fig. 3.30: Distant examples of rich & poor housing: Vista Alegre (Unknown in ISA 2007, p. 380) at Serra Mountain Range and private rooftop pool in Morumbi (Nelson Kon).

of transportation, air quality, soil sealing, stormwater, sewage and waste are resumed in the following part:

3.2.3 Transport and Air Pollution

The necessity of transportation and infrastructure generates indirectly a series of urban environmental problems linked to traffic, especially air pollution resumed here: The city's asphalted road network of 11.916 km (PRODAM, 1997) for the moving and stationary traffic, is the main cause for increased surface temperatures (the urban heat island) and increased runoff leading to inundations.

The moving traffic itself (estimations vary between 6 and 9 million vehicles in São Paulo) further generates waste heat, noise, and gas and particulate matter emissions. Especially particulate matter is dangerously high in São Paulo due to poor fuel quality in Brazil: diesel has 500 particulates per million, while in Europe and the US, diesel has 10 particulates per million (Oliveira and Page, 2008).

The fuel is inefficiently used because the road system is overloaded. Daily congestions summing up more than 100km (with maxima of almost 300km) during the rush-hours are common, causing costs estimated to almost R$ 2 billion per year (Cintra, 2008)

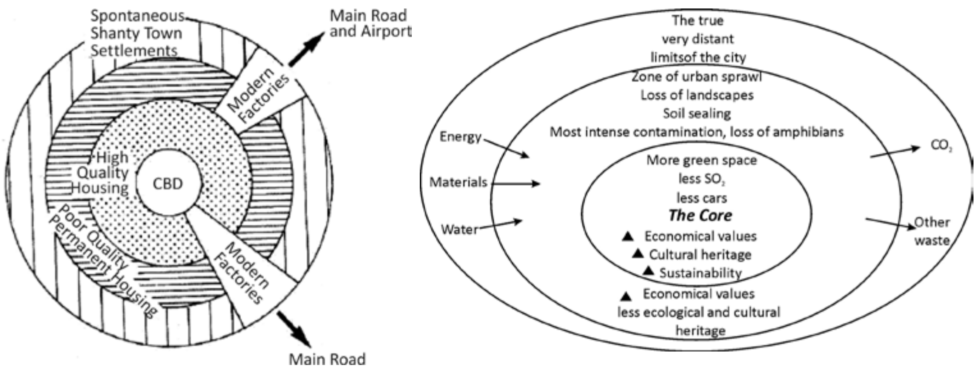


Fig. 3.31: LEDC Urban Land Use Model by Barcelona Field Studies Centre S.L. for São Paulo (left) and displacement of ecological conflicts in European cities (Martinez Alier, 2007)

[37] "A floresta vale mais em pé do que deitada". http://revistaepoca.globo.com/Revista/Epoca/0,,EDG79544-6009-491,00.html

According to Kohlhepp (1996) 90% of the air pollution is caused by traffic in São Paulo, (10% to industry). São Paulo is the fifth most polluted city in the world (Center of Atmospheric Sciences England). The mean pollution is 28.1 micrograms per m³ (the limit of the World Health Organization is 10 micrograms (Sangiovanni, 2009)

Indirect costs for the health system estimated to 334 million Brazilian Reais per year. Cardiorespiratory diseases such as infarcts, pneumonia, asthma and lung cancer are the most registered. According to Sangiovanni (2009) 20 persons per day die in São Paulo from air pollution.

Circa 30% of the 11 million inhabitants, own seven million cars. Since the "Rodízio System" was inaugurated in the central region it is quite common to have more than one car to to avoid the suspension of their car use a secondary one.

Metropolitan centers suffer from atmospheric pollution problems; the city of São Paulo for example, lives through dramatic situations during the winter months when air humidity is very low.

3.2.4 Water Access and Use

Another constant problem is water management. Especially the combination of torrential rainfalls (intensified by urban hear island), soil sealing and accumulation of street waste leads to inundations and water contamination. Parts of the sewage water (especially from informal settlements) are not treated which increases the pollution of the urban rivers.

Especially the draining of the swamp areas and the regulation of the meandering three main rivers Tiête, Pinheiros and Tamanduateí (see fig. 3.11) to increase urban land and to construct expressways (*marginais*) in a cost-effective way in the 1960s lead to an increase of inundations of these lowest regions of the city, also due to the increased intensity of urban rainfalls.

The land reclaim of these areas (from the 1920 on) further lead to real estate speculation and further impermeabilization along the expressways constructed in the 1960s. Sad de Assis and Frota (1999) e.g. suppose that it is in megacities of the Third World where the damages on the natural and built up environments take their most serious form due to the speculative use of urban space.

The annual mean water consumption per person is 65m² but varies highly with the living standard. More than 20% of the sewage are not treated direct discharge into the rivers, carry thus carry blackwater which causes also a huge sanitary problem (Jacobi, 2006)

The illegal appropriation, deforestation and occupation of environmentally protected regions where the spring regions of the drinking water are located (mamanicais) by favelas and the subsequent direct discharge of sewage into the barrages which supply São Paulo with drinking water.

Fig. 3.32: Direct contrast of favela Paraisópolis and Gated Community in the Morumbi district (Foto: Tuca Viera)

Fig. 3.33: Precarious housing near the Billings reservoir (headwaters) (above) and accumulation of street waste in French drains (below)

4. THE ROLE OF URBAN VEGETATION

This chapter outlines the role of urban vegetation in predominantly hot, cities like São Paulo, supporting the hypothesis (based on Taha, 1997, Alexandri and Jones 2006) that the benefits or urban vegetation increase with decreasing latitude. Most of the benefits from vegetation are linked to mitigation of urban climate, or in other words the equilibration of the urban energy and water balance lead to an increased quality of life and/ or urban sustainability (see chapter 2).

This chapter gives an overview on the pros and cons of broader urban vegetation, in a comprehensive list derived from literature research, compares chances and risks and points towards the following chapters which deal with quantifications (through modelling) of some of the impacts of vegetation seeking an approximation with a cost/ benefit relation.

The benefits are divided into two main parts: environmental benefits such as climate control, thermal comfort and energy efficiency, purification of resources through urban vegetation and social benefits, which are much more difficult to model, quantify or/ or to monetize.

Further the climatic role of plants which act as *buffers*, *pumps* or *living machines*, transforming radiation energy into water vapor linking water, energy, carbon and nitrogen cycles, regulating climate through shading and evapotranspiration is lined out.

In the last part indices for urban green required as numerical indicators for climate and plant interaction (ecological) modeling are analyzed. Such metrics are requires to model and estimate plant performance or so-called *environmental services* (see ISA, 2008), with numerical planning tools (see chapter 6). These metrics are difficult to obtain and predict from measurements, due to their tempo-spatial variations of leaf area within the seasons of the year and the growth/ sequestration rate and the life cycle of a plant.

Often these positive impacts e.g. of plants are referred to as *environmental services* because the improvements (or benefits) created by urban vegetation can be associated to monetary (and cultural) values. The simulations and estimations of costs and benefits of urban vegetation in São Paulo will be described in chapter 6.)

Urban vegetation has been indicated as one of the most efficient solutions to mitigate the undesired urban heat islands, heat stress and increased energy consumption for cooling caused by strong incident solar radiation in predominantly hot regions or cities like São Paulo/ Brazil.

Beyond the climatic benefits urban vegetation absorbs filters and stores, due to its physiognomic characteristics, natural and man-made environmental influences (like precipitation, CO_2 and other gaseous and particulate emissions, as well as noise) present in abundance in many dense, tropical megacities without consuming any primary energy. According to Corrêa da Costa (2005), this illustrates why the conservation and expansion of the natural environment means conserving energy passively and *vice versa*.

4.1 Plant Physiology and Climate

Most of the benefits gained from plants result according to Ong (2003) from plant metabolic and physiological processes. These include photosynthesis, evapotranspiration, respiration, uptake of minerals and nutrients from the air and ground, interlinking the complex air-gas-water-soil systems of the biosphere.

These plant physiological, natural processes which interlink energy and water, carbon

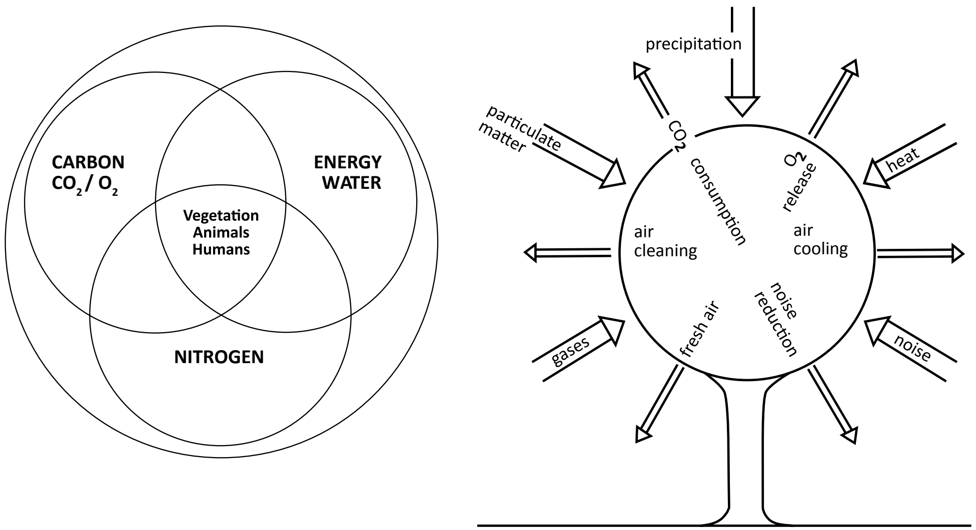


Fig. 4.1: Resume of ecological qualities and environmental services of trees (after Bernartzsky, 1982, left) and Simplified model which links the most important cycles which enable life within the biosphere (right).

and oxygen, as well as nitrogen cycles, are explained in detail in Jones (1992). Here only a resumed introduction on the complex functions of vegetation on the equilibrium of global to local energy and matter fluxes can be given.

4.1.1 Solar Radiation

Near surface climates (and life) are driven by the primary energy resource of the sun's electromagnetic radiation and the properties of the Earth's surface or land-use respectively. The surfaces trigger local heating and cooling of air and changes of air pressure which lead to horizontal air movements (wind). Beyond most important cooling mechanisms, antagonists to heating are shading, and the wet exchange processes of evaporation, condensation and precipitation which avoid the overheating of the system.

Solar radiation also enables the process of photosynthesis and thus indirectly animal and human life on the Earth's surface. Described in a simple way solar radiation is visible sunlight which is also sensible in the form of warmth (or heat) when the sun is above the horizon. According to the *electromagnetic theory* light (shortwave) and heat (longwave) energy only differ in their according to their respective wavelengths.

4.1.2 Reflection, Absorption and Transmission

When entering the Earths atmosphere solar radiation is filtered by a primary climate regulation element: clouds and dust. Within the atmosphere solar radiation is absorbed, transmitted or reflected by these (mainly water) molecules. As a result the radiation is scattered, becoming less direct and intense but more diffuse.

As shortwave (visible and near infra-red) radiation hits the Earth's surface or obstacles (such as trees, buildings etc.) it is partly being reflected and absorbed by opaque bodies, and transmitted by transparent or permeable bodies. The relation between reflection and absorption is defined by the albedo of the surface. The transmission is defined by the transmission and/ or attenuation coefficient of the material (in urban context for example glass) but radiation is also transmitted/ attenuated by trees.

The fraction of the radiation energy which is absorbed by matter is transformed into longwave thermal (or terrestrial) radiation which is emitted from the material in the form of radiant longwave radiation (heat). The heat flux from the surface can either be sensible or latent depending on whether the exchange process is dry or humid. According to measurements carried out by Oke (1989) the strongest influence of the thermal radiation is in urban context significant within a distance of 0.5 m from the surface, but this may be more significant in tropical cities.

Urban surface properties are highly responsible for thermal comfort in open spaces and on energy efficiency of the

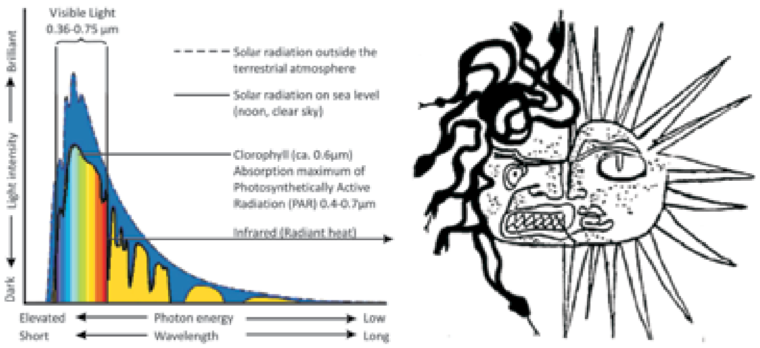


Fig. 4.2: The electromagnetic spectrum of extraterrestrial radiation after atmospheric absorption based on Duffie & Beckman, 1980 (left) and the beneficial and the dangerous side the sun in Olgyay and Olgyay, 1957 (right)

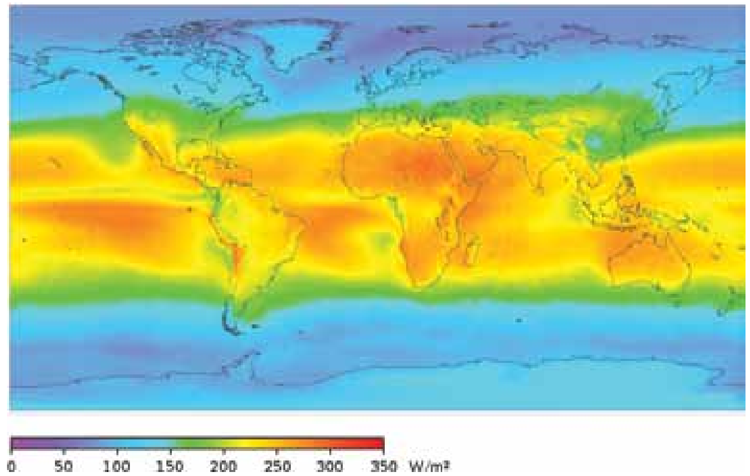


Fig. 4.3: Annual incident ultraviolet radiation over the Earth's surface is strongest in the Tropics of the southern hemisphere

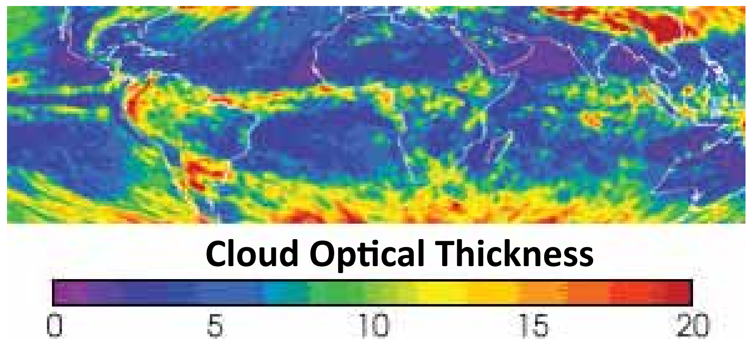


Fig. 4.4: Annual Cloud Cover Thickness - Clouds linking the energy with the water cycle reference to humidity. It shows (in combination with fig. 4.3) that the São Paulo region receives high solar radiation income due to little cloud cover throughout the year

surrounding buildings. Generally building surface albedo (reflexivity) is considered as most important, but the following analyses why also their humidity (e.g. plant surfaces) is important to decrease urban surface temperatures.

Transmission of Canopies

The secondary natural climate regulation element hit by the solar radiation (after the aforementioned clouds) are tree canopies which have highly complex properties - similar to those of clouds. The transmission (or interception) rate of solar radiation either through gaps between leafs or through translucent leafs depends mainly on the density and structure of the crown, which also defines the shading pattern which has important influence on the heating of the ground and on thermal comfort (see chapter 6.2.1).

In climates where not the maximum utilization of the sun is a main aim (see concept of *Solar Cities* of the North, in Behling, 1996) but rather efficient protection against solar rays, attenuation by clouds and tree canopies is often crucial to mitigate heat stress (see 4.2.3).

Temperate as tropical forests (like the Atlantic Forest biome) are multi-cultural, mutual ecologies with needs of co-existence and co-evolution. Within each layer of the forest, the availability of light is a limiting factor and in lower storeys only the so-called shade-tolerants are able to survive (Martin and Keefee, 2007).

Low albedo urban surfaces

When hitting dark, dry surfaces the absorbed shortwave radiation is transformed into outgoing longwave radiation leaving the earth as infrared radiation, increasing also the ambient air temperatures through convection on hot urban surfaces. The actual reason for the urban surface heat island (see fig. 3.25) are actually mostly dark surfaces (low albedo) such as bitumen roofs and asphalt streets, leading to increased surface and air temperatures and the emission of longwave re-radiation (sensible heat flux). Low albedo surfaces thus remain although widely applied, but worst option to mitigate the urban surface heat island – in fact they create it (see the *urban heat island* and *summer oasis*, chapter 3.2.1)

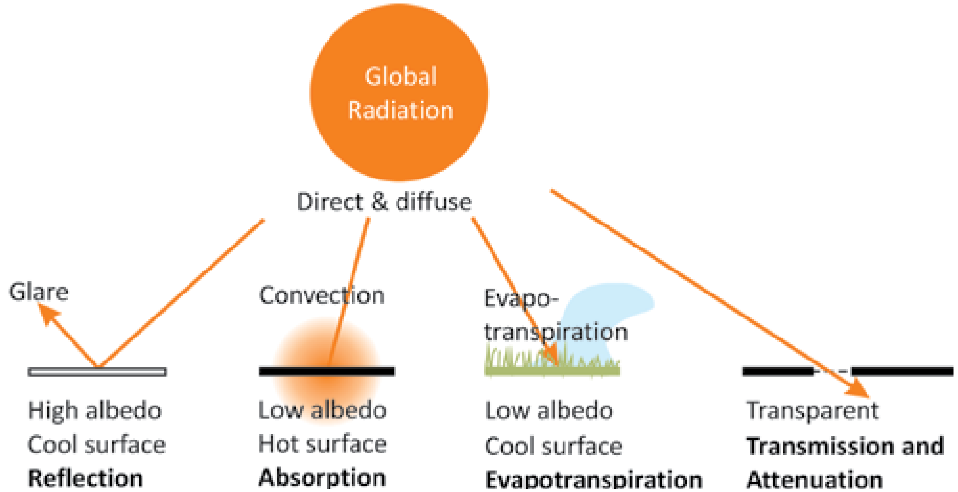


Fig. 4.5: Scheme of surface reflection, absorption and transmission of direct (and diffuse) solar radiation on opaque and transparent surfaces

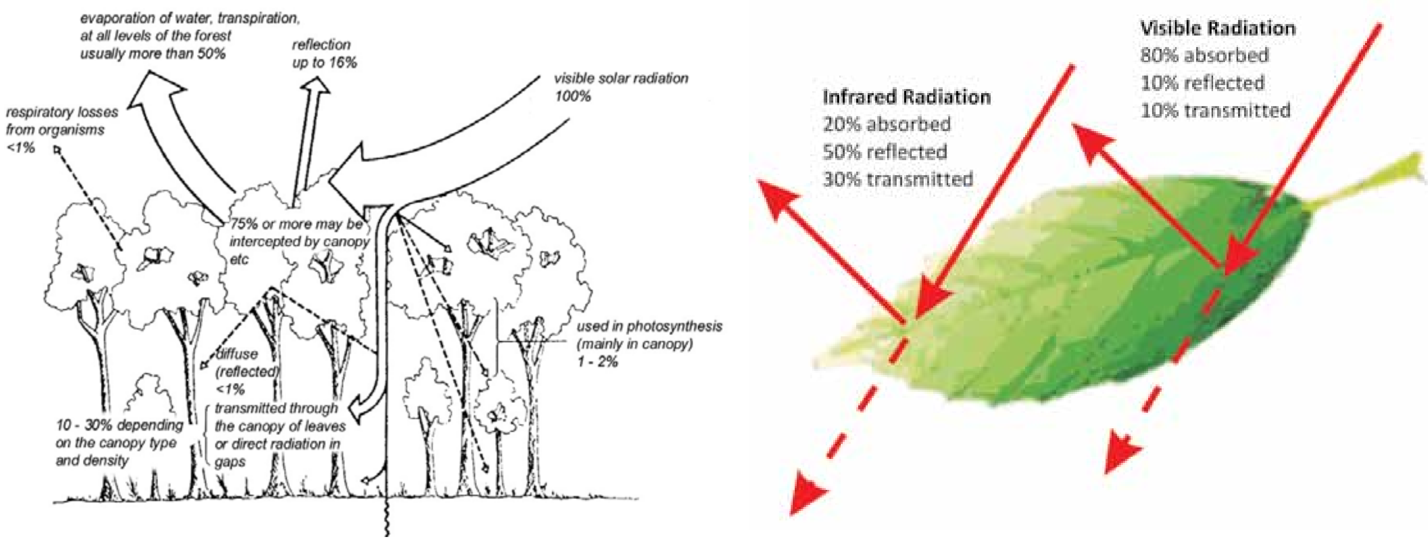


Fig. 4.6: Energy balance at different scales forest canopy (Packham et. al 1992) and single leaf scale (Brown and Gillespie, 1995)

4.1.3 Urban Whites versus Greens

Generally (white) high albedo surfaces are a modern building strategy to keep building envelopes cool especially applied common in the tropics. It has its origins in Bauhaus and Le Corbusier's *Radiant City* (see fig 3.12). In Brazil the aforementioned *MEC* in Rio (see fig. 3.14) was one of the first buildings with has highly reflective surfaces and white surfaces became also one of Niemeyer's trademarks.

Recently multiple reflections glare and increased radiant temperatures caused by highly reflective white (and especially specular mirror) surfaces are discussed and criticized (see Spangenberg, 2004). Glare problems have been documented in Brazil by Yannas and Corbela, 2003 and also by Roaf (2007) in temperate climate:

> "The reflectance of light and heat from metal and glass finished buildings can often cause chronic problems, to motorists, pedestrians and to adjacent buildings. (...) Some buildings like the Ontario Hydro Building in Toronto (...) actually focuses the sun's rays onto the sidewalk." (Roaf *et. al.*, 2007,p. 234)

The trapping of the solar radiation within the urban structure is actually more a problem of reflective glass fascades than of roofs, which are the building surfaces which receive the highest solar radiation income in low latitudes and can contribute more to decrease energy consumption. White roofs were proposed by Akbari *et. al* (1998) promoted as a public policy and applied in the United States.

But Akbari *et al.* (2001, p. 298) admit that building materials, however high their albedo, absorb heat and store it and that even white surfaces can become as much as 10°C higher than the ambient temperature" while Jones (1992) reports that plant surfaces, as a result of transpiration, do not rise more than 4–5°C above the ambient and are sometimes cooler).

According to an interview by Michon Scott with urban climate researcher Stuart Gaffin (2006) white surfaces may be cooler than dark surfaces, but they still trap heat. Compared to plant surfaces light urban surfaces are usually hotter.

Gaffin points out that white materials (especially roofs) get dirty quickly, reducing their ability to reflect sunlight and that even when they are kept clean, white roofs cause problems in reflecting the sunlight and degrading even distant surroundings thermally and visually. Or they might just bounce much of it off nearby buildings, heating up the immediate area. Due to multiple reflections between the buildings and in complex urban geometries the energy is trapped in street canyons increasing mean radiant temperatures (see Spangenberg, 2004).

Light-colored roofs hold another drawback for Gaffin. Researching mitigation options for the urban heat island Gaffin became aware of another issue that causes some cities as much hardship: stormwater runoff. The purpose of asphalt is to create an impervious called "the urban runoff island." Light-colored roofs might absorb less of the Sun's energy than dark roofs, but they do nothing to mitigate runoff.

Comparing "whites" to "greens", Gaffin and his colleagues presented the results of their 2002 New York City heat wave study at a science meeting (in 2006) considering white roofs the winning strategy, but they soon changed their mind finding that plant surfaces are generally (even) cooler than white surfaces. In tropical urban settings it was found that the surface temperature of a greened roof was up to 12ºC degrees cooler than a relatively new and reflective concrete roof (with a low albedo of 0.31).

4.1.4 Evapotranspiration Cooling of Plant Surfaces

The definition of the fractions of absorption, transmission and reflection of plant canopies is by far more complex than for urban construction materials, such as glass, due to the complex architecture of tree crowns (for example), heterogeneous leaf distribution, different species etc (see chapter 4.2).

According to Oke (1987) for trees roughly a fraction of 20% transmission, 55% absorption and 25% reflection can be assumed. Brown and Gillespie (1995) give 80% for absorption and 10% each for reflection and transmission. However, such generalizations are complicated because these parameters very strongly for most species, depending on the season

Fig. 4.7.: Highrise buildings with (mirror) glass façades causing glare, Jaragua building (above) and building at Paulista Avenue (below)

of the year and within the life-cycle of the plant.

Tropical leaf albedos are often low and forest structure are dense and dark, so that generally only a very low part of the radiation is reflected back skywards and most radiation is trapped and absorbed in the tree canopies. According to Oke (1987) the dependence of the albedo upon the solar altitude also explains why tropical albedos are usually less than those for similar surfaces at higher latitudes.

The highly complex *multiple reflection* and diffusion of solar radiation skywards, into and through the canopy, depends on many parameters, like leaf albedo and transparency, leaf angle, crown structure etc. and makes calculations of radiation extinction (and transmission) extremely difficult. (see Jones, 1992 and chapter 5.1.1).[1]

The absorption of the radiation in tropical vegetation is usually > 90% and enables a maximum transfer of energy into biomass through photosynthesis and thus plant growth on one hand and protection of the ground through shade on the other, creating a special microclimate which improves the conditions of the plant in the ecosystem community.

Low albedo surfaces which absorb a maximum of solar radiation to enable maximum transpiration appear to be natural cooling strategy of tropical biomes which applies to the evolution of both leaf and skin albedo.

The principle of conservation of energy (the *First Law of Thermodynamics*) states that energy cannot be created or destroyed, but only changed from one form to another: In contrast to the direct radiation which hits dry urban low albedo surfaces the solar radiation absorbed by plant leafs is not transformed into sensible heat, but mainly into latent heat, through the evapotranspiration of water through the plant metabolism. This leads to lower air temperatures and higher air humidity within the crown and its immediate surroundings.

The air masses are moved into the leeward direction of the canopies, but for isolated trees these microclimatic modifications are rapidly diffused in the air volume which traverses the tree crown by the wind (McPherson and Simpson, 1995). The magnitude of the cooling effect was found to increase with rising number of trees (Shashua-Bar and Hoffman, 2004) and is significant especially on the lee sides of urban parks (see Yu and Hien, 2006).

A mature tree evaporates up to 400 liters of water per day through millions of pores (leaf stomata) by pumping water enriched with nutrients through the tree structure by osmotic suction/ pressure. The metabolite process of photosynthesis though evapotranspiration further cools the leaf surfaces passively by transforming liquid water with the aid of solar radiation into water vapor (change of aggregation).

The relationship between latent and sensible heat flux is described by the

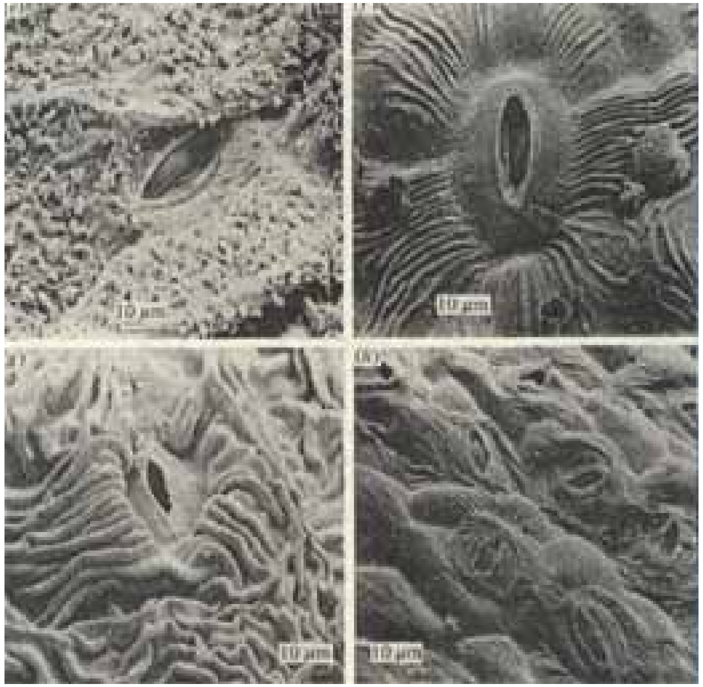


Fig. 4.8: Microscopic photographs of representative stomata from the leafs of different species from Jones 1992 (above) and Evaporation - The transformation of liquid water into water vapor requires large amounts solar radiation and cools surfaces (below) (Behling p. 205/206)

[1] Ray tracing computational studies are highly recommended for future work

Bowen Ratio. The evaporation cooling effect is very powerful because the amount of energy necessary to transform liquid water into vapor is surprisingly high: 680 kWh/ m^3 water, which means that the evaporation of 1g of water per minute requires 41W.

Grey and Deneke (1978) considering that a single tree transpires approximately 380 liters per day calculated a cooling effect equivalent to five mean air conditionings (2500 kcal/h) going 20 hours per day. But as mentioned these microclimatic modifications are, rapidly diffused by the wind and do not benefit directly nearby buildings.

Especially important in urban context is the combined absorption and reflection of the tree canopy, generating shadow (attenuation of solar radiation) as well as cool leaf and urban surfaces below the canopy. The combined absorption/ reflection effect of the canopy leads (in contrast to the transmitted /intercepted direct solar radiation) to thermal comfort and increased energy efficiency of shaded buildings.

The experiments (fig. 4.9) presents surface temperatures of different materials and plants measured *in loci* in São Paulo's central conditions, (Luz Neighbourhood) on 19th of December 2006 with infra-red contactless equipment TFA 31.1108 by the author. Surface temperatures are a meaningful indicator to identify the heating and cooling performance or urban elements (building materials, plants etc., see also chapter 6.2.1)

They show that radiation heats up the surfaces it hits, dry and dark surfaces much more that reflective and humid ones (the latter due to the effect of evaporation cooling). Shade leads to cool surface temperatures below the shading element and is considered to have a more important direct impact on thermal comfort than the evapotranspiration cooling effect on air temperature.

However the metabolite performance (evapotranspiration/ photosynthesis rate) of plants reciprocally depends on

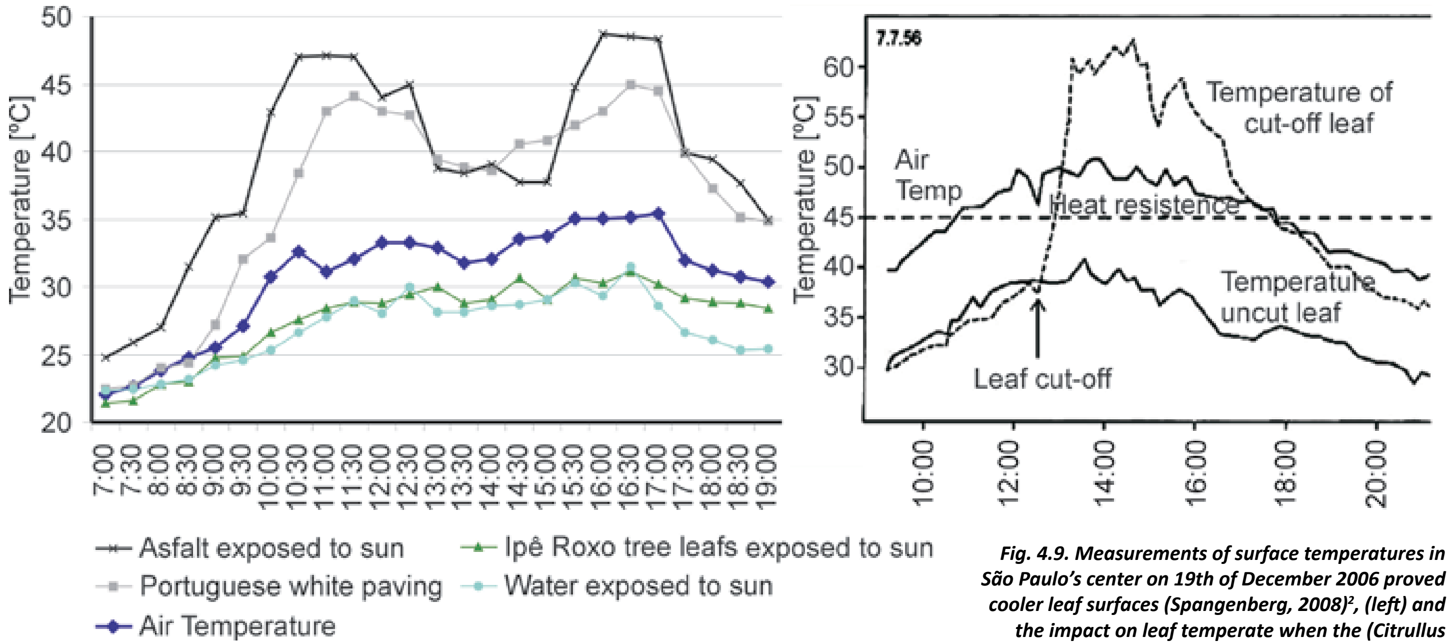


Fig. 4.9. Measurements of surface temperatures in São Paulo's center on 19th of December 2006 proved cooler leaf surfaces (Spangenberg, 2008)[2], (left) and the impact on leaf temperate when the (Citrullus colocynthis) leaf is being cut off and does not receive water for evapotranspiration (Larcher, 2001) (right).

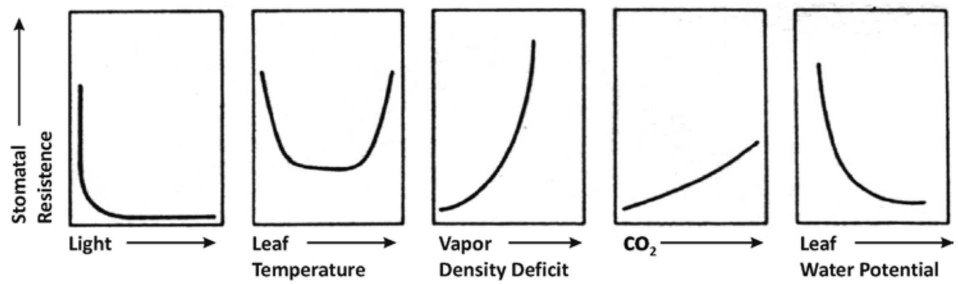


Fig. 4.10: Schematic relations of the dependency of stomatal resistance on different climatic factors which limit or stimulate plant metabolism rates (see Oke 1987)

[2] First published en AU-Arquitetura & Urbanismo Year 23, No. 167, February 2008

(micro-)climatic conditions, especially air temperature and water availability. Plants are sensible to water-stress, heat stress etc. (see Oke, 1987), which can lead to closure of the stomata (in order to protect the plant organism against uncontrolled water losses) leading to an increase of leaf temperature (see fig. 4.9 right).

A climatic situation when the air is highly saturated with water vapor, close to the dew point, a quite typical situation in São Paulo during the summer the evaporation rates decrease due to vapor pressure.

4.1.5 Carbon Sequestration and Growth

Typically, 90% of the energy contained in the wavelengths between 0.4 and 0.7 µm (PAR) is absorbed by a leaf, transforming radiation energy into vapor. The remaining 10% of the light is transmitted through the leaf and becomes enriched with far-red light (Lee, 1985).

But only 0.05%-0.25% of *photosynthetically active radiation* (PAR) absorbed during the day is transformed into biomass while the largest part of the incident energy of trees is transformed to support the metabolite transpiration process: leafs absorbing (inhaling) carbon-dioxide (CO_2) from the atmosphere and exhaling oxygen (O_2) during the day by breaking up the molecular structure of the carbon-dioxide liberating oxygen and sequestering carbon.

Circa 30%-50-% of wood is carbon. A constant of 3.67 can be applied to calculate the rate from absorbed CO_2 to sequestered carbon. The evapotranspiration process enables the metabolite photosynthesis and respiration process of plants absorbing inhaling carbon-dioxide (CO_2) from the atmosphere and exhaling oxygen (O_2) during the day by breaking up the molecular structure of the carbon-dioxide liberating oxygen and sequestering carbon.

4.2 Parameters for Urban Vegetation Cover

This chapter gives an overview and explores methods to measure plant properties as metrics (or numerical parameters and indices) and input data to simulate (e.g. climatic) benefits of urban vegetation. Leitão and Ahern (2002, p. 74), noted that there are “literally hundreds of metrics developed” and that these metrics are “frequently strongly correlated, and may be confounded”.

Among the metrics, vegetation land cover and leaf area (per ground unit) were separated as key parameters. Especially leaf area (index or density) has become a common parameter to simulate and thus estimate plant-physiological exchange processes and especially climatic benefits.

According to Nowak (1994) most of the benefits of plants can be shown to increase directly or indirectly with an increase in leaf area. Leaf area drives controls the within- and the below-canopy microclimates, determines and controls canopy water interception, radiation extinction, water and carbon gas exchange and is, therefore, a key component of biogeochemical cycles in ecosystems.

Leaf area depends mainly on specie, crown architecture (genetic information) and local microclimatic, growth conditions, consequently health etc. but a limitation of this ecological measure are tempo-spatial variations of leaf area according to the seasons (deciduousness) and the plant growth (life cycle). Consequently every measure describes a moment so that leaf area can not really be considered a stationary parameter.

Since Moffat and Schiller (1981) point out that any use of vegetation for improving the microclimate has to exploit judiciously these properties according to site comfort requirements this chapter seeks for leaf area of typical isolated street trees in São Paulo.

4.2.1 Vegetation Land Cover

Vegetation cover and its change within timeframes are usually calculated in hectares or square meters from land use classifications, derived from aerial or satellite photos. The classifications of remote sensing images are calibibrated from typical leaf or forest albedos.

It is an interesting fact, that it is common in Brazilian (non-scientific) reports to give areas of deforestation in football field size (90m x 120m, 1.1 hectares), especially in the Amazon Region, but as well in peripherical regions close to megacities, like São Paulo, because this means a descriptive, imaginable size.

It should be pointed out that generally building shadows and vegetation covers above low-rise buildings cause problems in distinguishing the vegetation cover in land-use maps derived from satellite images in urban regions. For classifications (two-dimensional indices) it is important to additionally to include (aside from distribution) detailed information on the vegetation type (e.g. tree, scrub, grass), understory cover information (soil, sealing etc) and/ or other qualitative or quantitative indicators on health and density of the green areas.

In cities, green spaces are often correlated with the number of inhabitants, per district or per municipal areas (SVMA, 2000). For comparative mean numbers of square meters of green spaces per inhabitant in large Brazilian see chapter one.

Many articles mention different values (ranging between 8m² and 20m²) of a minimum proportion of green area per inhabitant proposed by the *United Nations* (UN), the *World Health Organization* (WHO) or the *World Food Organization* (FAO) but do not indicate the exact source (Christina and Braga, 2005). A personal contact with WHO (see annex A II) has affirmed that, also by 2007, such guideline did not exist. It must be added that besides from the mentioned qualitative and/or quantitative indicators (see 6.3) the establishment of such guidance value should consider urban land use, population density and the particular climate of the region or country.

Ong (2003) points out the necessity of an ecological measure for urban green, but also that no official guidelines exist yet. However Lang and Schöpfer (2005) report that Berlin's *Local Agenda 21* determined a guidance value of 6m² per Inhabitant (for green close to tenements) and 7m² per inhabitant (for green close to dwellings).

4.2.2 Weighted Green Index (GIw)

Lang and Schöpfer (2005) introduce an interesting and more detailed indicator *Green wheightened Index* (derived from the German concept "*Durchgrünungsgrad*"), which analyses distances and density of constructed and planted spatial arrangements as one indicator for *quality of life* in Austria.

Using high resolution images from low-altitude flights, the authors classified the images in 14 classes, 10 classes for green (including water) and 4 for non-green pixels, analyzing fuzziness values. Further within cells of 1ha (100m x 100m) the mean footprint proportion of multi-family houses and mean values of distances between buildings the cells evaluated to additionally weight the localization of the green. The final results of the *Weighted Green Index* were presented in four classes.

4.2.3 Leaf Area Index (LAI) of typical urban Trees

Leaf Area Index is defined as the total one-sided area of leaf tissue per unit ground surface area (Watson, 1947) has become the standard measure for vegetation cover from global scale to single tree scale. According to Ong (2003) the methods to measure leaf area index at urban tree scale can be divided into two main categories:

- **Destructive, direct methods** The direct methods essentially involve physically calculating the average area of individual leaves taken from a plant or parts of a tree and then extrapolating to the stand or the entire tree. According to Peper and McPherson (1998) destructive methods harvest all leafs of an individual tree and scan their total area and obtain more exact results than other methods but are also time consuming and more expensive.

- **Non-destructive, indirect methods.** Indirect methods in general involve determining light transmittance values through the plant canopy of individual trees or can be derived for canopy cover from remote sensing measurements of Earth's surface albedo/ absorption of PAR.

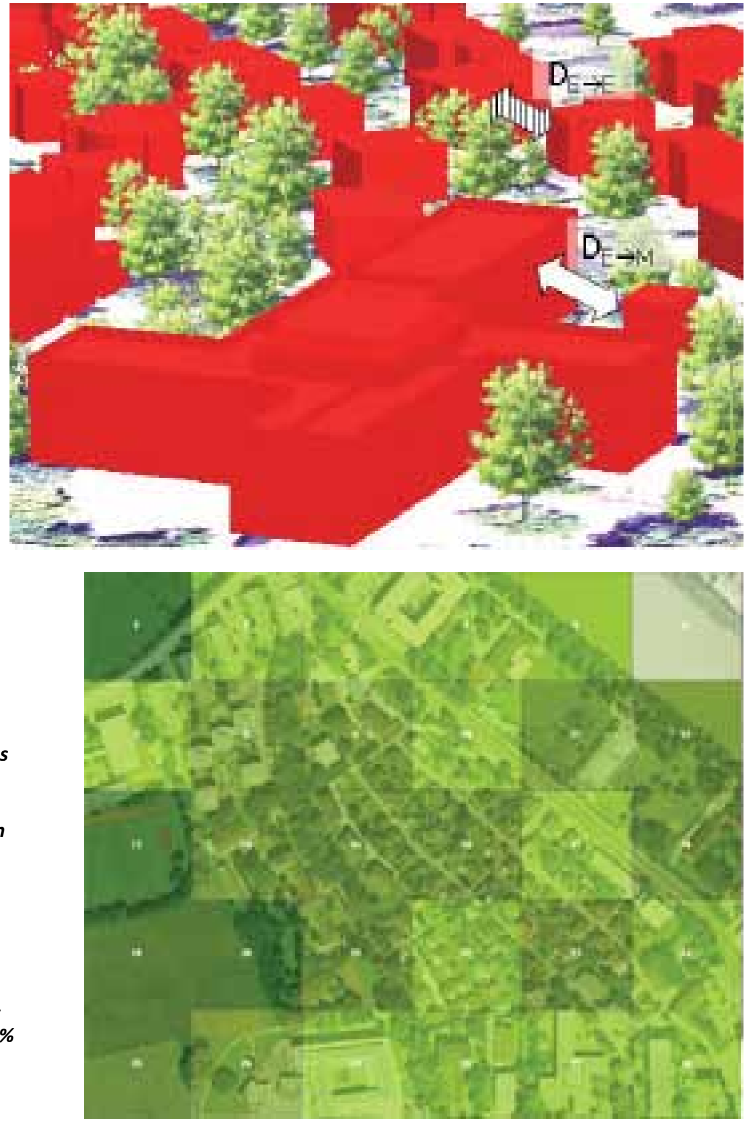


Fig. 4.11: Constellations of buildings which can interfere negatively the perception of green space (above) and the Green Wheightened Index within cells of one hectare based on classification and building constellation. The colours refer to 0 – 25%, 25 – 50%, 50 – 75% and 75 – 100% (below) (in Schöpfer and Lang, 2005)

Here only non-destructive methods (which can be applied to satellite images or measurements of isolated urban trees *in loci*) will be shortly outlined. Destructive methods were also considered to estimate leaf area of local typical street trees in São Paulo but not applied.

Leaf Area Index (LAI) can be obtained from high resolution satellite or low-altitude flights or be measured *in loci*, even for isolated urban trees. Remote sensing using satellite images are based on a discovered linear relationship between the *Normalized Difference Vegetation Index* (NDVI), derived from the aforementioned images, and *Leaf Area Index* (LAI) (Green and Clark, 2000). *Normalized Difference Vegetation Index* (NDVI) is calculated using values of red and infra-red bands of satellite photographs between 666.5 and 752.8 nm. A regression formula linking NDVI values and LAI is then used to derive LAI thematic maps.

Scurlock *et al.* (2001, cited by Ong, 2003) for example give benchmarks of LAI 1 for grass, LAI 3 for scrub and LAI 4 for trees (see fig. 4.12). Peper and McPherson (1998 and 2003) carried out distinctive research orientated towards the determination of LAI values of isolated trees in urban conditions, applying and comparing different methods.

Green Plot Ratio (GPR)

Ong (2003) proposed a *literally green planning indicator* or *ecological measure* called *Green Plot Ratio* (GPR), based on the findings of modeling environmental benefits and leaf area or LAI (leaf area index) respectively. According to the author this metric, is based on the common biological parameter of the leaf area index (LAI) and makes an analogy to the to the building plot ratio (BPR), comparing the number leaf storeys (see fig. 4.12, right) to the number of building storeys on site, seeking for an equilibrium between constructed an vegetated mass. Consequently the *green plot ratio* is simply the average *Leaf Area Index* (LAI) of whatever greenery on site.

Measurements of leaf area of isolated urban trees

Only few studies which measure the bioclimatic qualities (like leaf area, its seasonal change and attenuation/ transmission of solar radiation) of typical street trees in Brazil were found especially when compared to research carried out in the United States e.g. by Nowak, Peper and McPherson etc.

Individual street trees, species of *Atlantic Forest* biome of the south of Brazil were measured by Weingartner, (1994), Piertobon, (1998 and 1999), Bueno (1998 and 2003), Spangenberg *et. al.* (2007, unpublished) and Abreu (2008) applying different methods. Interestingly all studies were carried out by architects, engineers and urban planners and question for example "whether trees are a commitment or a conflict" (Pietrobom 1998) with the energy efficiency of low rise buildings, analyzing the question of decreased thermal load versus decreased daylight access.

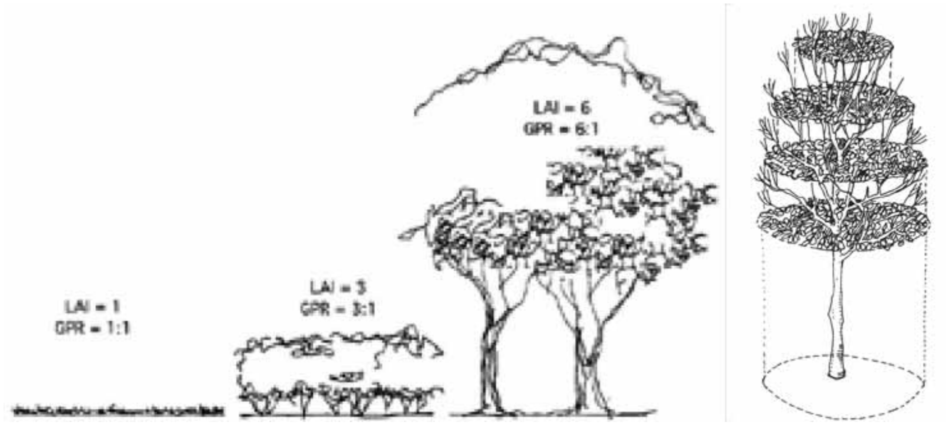


Fig. 4.12: Leaf Area Index of grass, scub and trees by Scurlock et al. (2001) including Ong (2003) Green Plot Ratio (GPR) modified (left) and tree with LAI 4 by Trowbridge and Bassuk (2004) (right)

The authors mentioned measured transmission, attenuation or leaf area index (LAI) of 13 (approximately one third) amongst the most typical 40 street tree species planted in São Paulo (PNUMA/ SVMA, IPT (2004) in different seasons. Most of the measured individuals are native species of the *Atlantic Forest* biome, semi-deciduous, thus climatically adapted and thus robust (e.g. Jacarandá, Ipê Amaleo, Sibipiruna, Cedro, Aroreira salsa, Alecrim de Campinas and Quaresmeira). The measured trees were mostly mature and have a mean height, as well as crown diameter more or less 10m (summarized in table 4.2).

According to Ong (2003) hemispheric and other photographic methods, are based on the gap fraction theory. The theory relies on the fact that leaf densities in tree canopies are unevenly distributed and that gaps exist between these leafs through which unattenuated light transmission solar penetration is assumed.

A general problem of photographic methods are the definition of the threshold between transmitted (white) and attenuated (black) in the pictures, due the necessity to define a threshold for grey (fuzzy) pixels. Recommend timeframes are morning and evening on cloudless days because cloud cover and direct sun on the lens can lead to dissolving effects near the sun (diffuse light) which complicates the photographic measurements.

According to Ong (2003) the estimation of LAI using linear canopy measurements is based the fraction between canopy transmittance/ attenuation (transparency, porosity) defined by the *Beer-Lambert law.* The law assumes that light is attenuated exponentially as it travels through the canopy in accordance to the (stand specific) extinction coefficient, k. The incident shortwave radiation (light) below the canopy, Qi, is related to the incident shortwave radiation above the canopy, Q_0, and LAI, by the natural logarithmic relationship:

$$Q_i = Q_o\, e^{-k\, LAI} \qquad (1)$$

The assumption that the canopy is randomly dispersed is a necessary simplification that enables mathematical manipulation of collected data (see limitations).

Software which analyzes light transmission through tree canopies using hemispheric photographs is for example *WinScanopy* and *Gaplight Analyzer*. The values obtained by these software produce estimates of LAI, leaf distribution, mean foliage inclination (leaf angle distribution), transmission coefficients for diffuse and radiation penetration, and extinction coefficients. In Brazil this photographic method was applied by Piertobon (1998).

Pyranometers and/or Radiometers

Another ground based method to measure the relation between radiation outside and below canopies was applied for common species in the State of São Paulo by Bueno *et. al.* (1998, 2001), Abreu (2008) in Campinas/ Brazil and by Pietrobon (1998) in Maringá. These methods combine direct and indirect, long and shortwave radiation measurements using a combination of pyranometers and radiometers.

The results of the Brazilian studies are considered to have a good exactness because they consider the complex self-shading and multiple reflections inside of the crown (see Jones, 1992) by measuring also the diffuse radiation below the canopies. The results of attenuation and transmission were applied in the Bears Law (1) to calculate LAI and are resumed in table 4.2.

Other instruments measure hemispherical (long and shortwave) radiation below canopies to determine LAI are *Licor LI-2000 and LI-3000* and *Decagon AccuPAR*[4], to measure *Photosynthetically Active Radiation* (PAR) outside and below the canopy.

Empirical formula to estimate Leaf Area

Another method worth mentioning to calculate leaf area from few parameters was elaborated by Nowak (1994). The author and his team measured *shading coefficients*, height and diameter of typical local urban trees (top 20 species) in Chicago (United States) to developed an empirical logarithmic formula (r^2=0.91) to estimate leaf area of isolated trees with heights and diameters of up to 12 meters.

Fig. 4.13. Hemispheric photograph of tree canopies in São Paulos Ibirapuera Park with fish-eye lens on 10th of October 2007 (left) and experimental black and white threshold definition using Gap Light Analyzer[3], no results obtained (right).

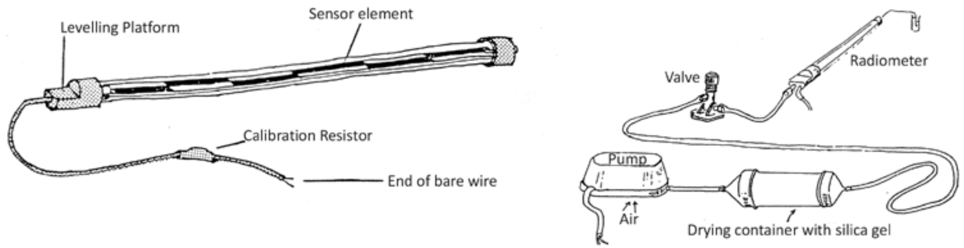


Fig. 4.14: Equipment used by Bueno (1998) Linear Pyranometer (Delta-T, 1993) (left) and Radiometer (Delta-T, 1993) (right)

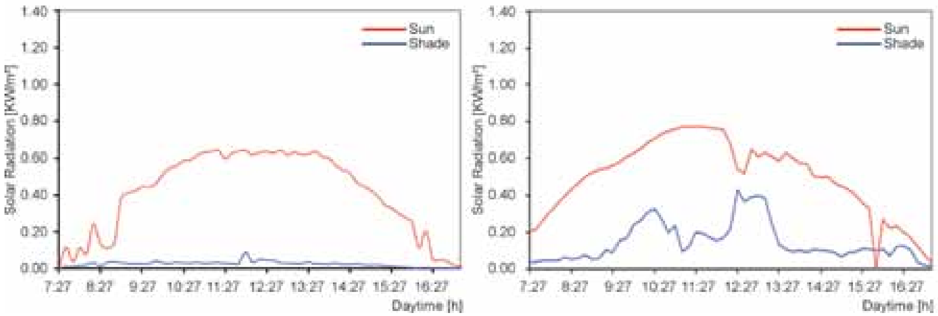


Fig. 4.15: The graphs by Bueno et. al (2001) compare measurements of mean solar radiation measured with pyranometers outside and below the crowns (attenuation/ transmission) of Cinginium jambolana during 31st of June 2000 (left) and Schinus Molle during 12th of June 1999 (right)

[3] http://www.ecostudies.org/gla/ <access on 27th of June 2009>
[4] http://www.decagon.com/ <access on 27th of June 2009>

$Y = e^{-4.3309 + 0.2942H + 0.7312 D + 5.7217 Sh - 0.0148S} + 0.1159$

where Y = total leaf area (m^2), H = crown height (m), D = crown diameter (m), Sh = shading coefficient and $S=\pi D(H+D)/2$. The correction factor (0.1159) was added by Nowak for local adjustment of the formula for urban trees in Chicago.

The application of Nowak's formula for typical street trees in São Paulo led to over-estimations of leaf area, compared to results of other models but the approach in combination with growth rate models (see Peper *et. al.* 2001 and American Forests 2002) is promising in order to predict increase of size, leaf area and benefits in future scenarios.

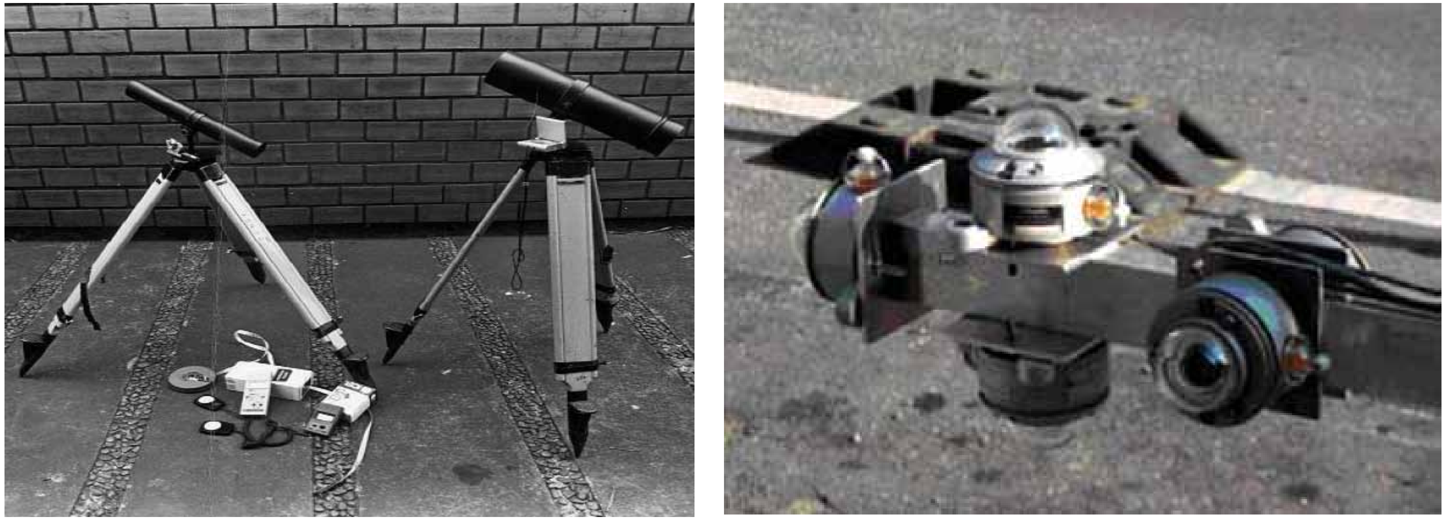


Fig 4.16: Tube Luximeters used by Pietrobon (1999) (left) Set of pyranometers used by Ali-Toudert (2005) in Freiburg to measure mean radiant temperature.

Experimental application of CD method

Literature review on measuring leaf area for microclimate modeling (see above) indicated that estimating leaf area for isolated trees is not a simple and time-consuming task, especially due to equipment, object trees and luminous conditions.

Looking for a more effective, simple and reliable photographic method to estimate leaf area of typical, isolated urban trees in São Paulo we found an article by Peper and McPherson 2003, which compares methods to estimate leaf area. The authors found that the most time and cost-efficient method is their self proposed lateral color digital image processing *CD method*, originally developed in 1998, and revised for digital photography in 2003. The authors further found, that the CD method showed good correlation with true leaf area (R^2 >0.71)

This photographic method relays on lateral transmission of indirect light through the isolated tree crowns analyzing pictures of trees taken on elevation. The concept of leaf area estimation based on *Silhouette Area* also evolves the understanding that, in a three-dimensional crown, certain portions of leaf area remain "unseen" due to leaf overlap, resulting in an underestimation of actual leaf surface area, while inclusion of the stem results in an overestimation (Peper & McPherson, 1998).

An experimental study was carried in cooperation with Dr. Erik Johansson (Post-doctorate of Lund University Sweden) and Paula Shinzato (Master degree Student at University of São Paulo) in São Paulo's Ibirapuera Park; on 07th of October 2006 (spring time) applying the analogue *CD method* (Peper and McPherson, 1998). The following steps were carried out *in situ* and subsequently using image analysis software in the laboratory.

Step 1: Analogue elevation photos of isolated trees were taken on 24 x 36 mm negative film (2:3 ratio). For greater accuracy, additional photographs are taken at positions perpendicular to each another and of (at least) two individuals per specie. A reference poster-board was positioned and tape measurements of the distance between camera and tree and of the crown diameter were executed.

Step 2: Photos were printed on 10x15cm and scanned with 300dpi (dots per inch).

Step 3: The image were resampled from original 300 dpi to 72dpi and the crowns isolated, using *Magic Wand* tool of Adobe Photoshop

Step 4: Real Height and Crown Base were calculated from the pixel relation given by the poster-board.

Step 5: Subsequently the crown dimensions were cropped to obtain Crown Height and Crown Width in Pixels and Centimeters in the 72dpi picture and the Crown Frame Area picture saved for image analysis)

Step 6: The enlargement ratio was calculated by dividing distance of camera from tree divided by focal length

Step 7: To calculate Crown Frame Area CFA in cm² both dimensions were multiplied with the negative to picture scale and divided subsequently by the enlargement ratio (see step 6)

Step 8: The CFA picture generated in step 4 was loaded into Sigma Scan (Image Analyzing Software), set Colour Threshold and measure number of pixels using the pixel count function).

Step 9: The number of pixels of the CFA was the divided by the total number of pixels of the whole picture to obtain the Silhouette area (SA) ratio.

Step 10: Finally Leaf Area (LA) = % Silhouette Area (SA) x Frame Area of Crown (CFA) and the Average Leaf Index by dividing Leaf Area by Crown Projection Area (CPA) were calculated.

It was found *in situ*, that it is difficult to find urban trees in front of homogeneous light surfaces (or sky) without interferences of other urban elements e.g. tree canopies (Step 1). Further, executing picture analysis and calculations, that setting the colour threshold (see step 8) bears difficulties mentioned for other photographic methods. Although doubts remain about the exactness of this method the results can be regarded as reasonable estimations when compared to results obtained with other methods.

The results derived from this study and those derived from literature research on

Fig. 4.17: Image of Pau Ferro (Caesalpinia leiostachya) taken in Ibirapuera Park on 07th of October 2006 at 20 meters distance (left), absolved and isolated in Photoshop (middle) and threshold/ pixel count of Silhouette Area in Sigma Scan to calculate Leaf Area (right)

Popular/ scientific Name	Tree	Height (m)	Crown diameter (m)	Crown proj. area (m²)	Total Leaf Area (m²)	Leaf Area Index. LAI (m²/m²)	Avg. LAI (m²/m²)
Alecrim de Caminas	1	7.9	7.9	54	179	3.3	
Holocalyx balansae	2	8.3	7.8	49	142	2.9	3.1
Alfeneiro	1	8.1	10.7	77	185	2.4	2.4
Jacaranda mimosaefolia	-	-	-	-	-	-	-
Jacarandá	1	10.7	8.8	61	122	2.0	
Jacaranda mimosaefolia	2	9.9	10.7	93	110	1.2	1.6
Pau Ferro	1	11.6	12.1	109	130	1.2	
Caesalpinia ferrea var. leiostachya	2	7.8	12.7	131	132	1.0	1.1
Quaresmeira	1	5.6	9.8	71	164	2.3	
Tibouchina granulosa	2	7.6	6.2	35	63	1.8	2.0
Sibipiruna	1	8.1	12.0	102	196	1.9	
Caesalpinia peltophoroides	2	8.6	14.2	131	234	1.8	1.9
Tipuana	1	15.8	13.3	178	1063	6.0	
Tipuana tipu	2	11.5	18.3	258	745	2.9	4.4

Table 4.1: Results of LAI of 13 individuals (7 species) see also table 4.2

Brazilian experiences of measurements of typical street trees by Bueno *et. al.* (1998, 2001), Abreu (2008) in Campinas/ Brazil and by Pietrobon (1998) in Maringá are resumed in table 4.2. Leaf area index was calculated according to the *Beer-Lambert law* (1):

LAI = LN((100-y)/100)/-k

where y is Attenuation in %
and k the extinction factor (here assumed 0.5)

4.2.4 Leaf Area Density

As pointed out by Bueno *et. al* (1998) measuring (and simulating) the microclimatic alterations caused by vegetation canopies is a difficult task. To model the influence of the crown on the wind-field, sky view factor, and extinction factor of solar radiation (or light) within and below the canopy, dispersion of pollutants, evapotranspiration rate etc. in detail, spatial, a numerical description than leaf area becomes necessary.

Leaf Area Density in square meters leaf area per cubic meter tree crow (m^2/m^3) and describes the leaf area distribution within the canopy at usually at 10 heights (storeys). LAD profiles thus include indirectly) information about the crown shape. The LAI is the sum of the values of each storey.

4.3 Limitations and the need for Growth Models

Aside from the need for metrics of urban green (Ong 2003) the leaf area can not be considered an absolute value due to seasonal changes (deliciousness) and plant growth, which must also be modeled (at least at micro-scale). Generally limitations and challenges of estimating leaf area are:

- Heterogeneity of leaf distribution and leaf angle within individual crowns
- Interferences between individual tree crowns
- Deciduous and semi-deciduous species represent significant tempo-spatial variations of leaf area (and thus transmission of solar radiation) throughout the year. Tropical biomes like the *Atlantic Forest biome* include many evergreen trees which represent smaller variations (see e.g. Maass, *et.al* 1994).
- Estimating the growth potentials according to genetic potentials of the species and individual local micro-climatic conditions to predict future benefits. Considering seasonal change and growth of leaf area is important especially to model direct benefits at micro scale.

Peper *et. al.* (2001) proposed a method to calculate the growth of leaf area of typical street trees species in the U.S. by deriving regression formulas and analyzing relationships between tree height, diameter-at-breast-height (DBH), crown diameter an leaf area of individual trees. Their results show that growth is not linear but can be approximately determined by natural logarithms.

Another sophisticated growth model for typical species in the U.S. was created by American Forests (2002). It is supported by composite tree species database of more than 13,000 trees and 264 species typical in North America. The model allows dynamic growth modeling applying growth rate formulas linked to climate. It determines for example, the height change by multiplying the number of growth years by the height growth rate, while the diameter-at-breast-height (DBH) change is projected by adding the existing diameter to the number of growth years multiplied by the diameter growth rate.

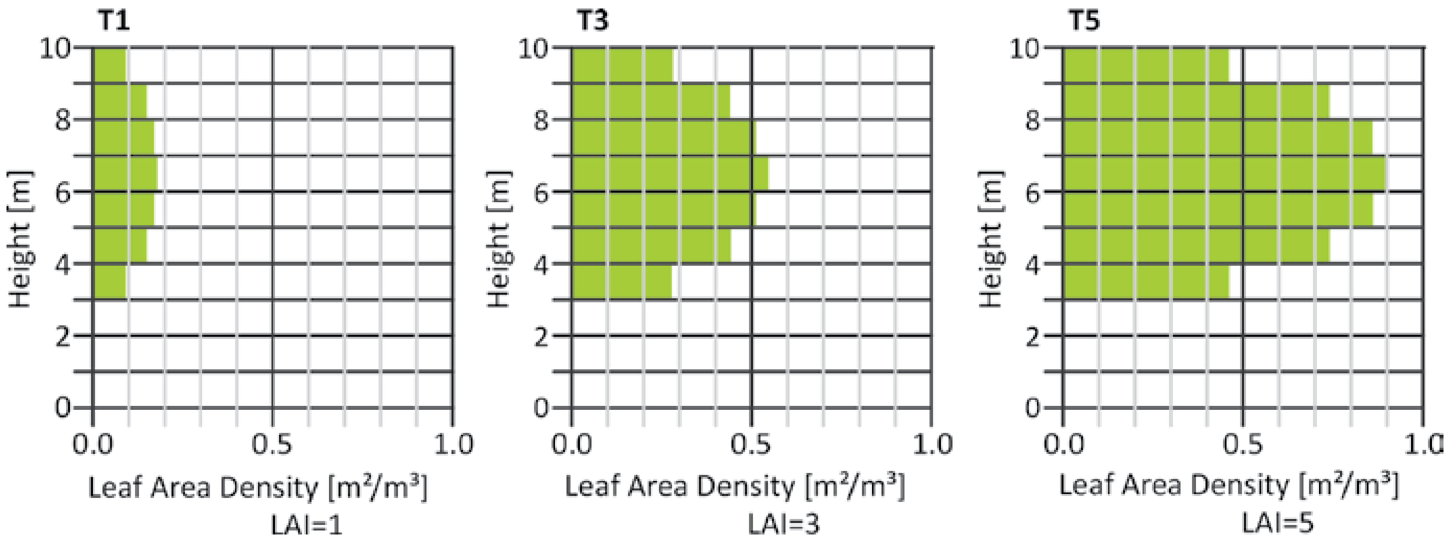


Fig. 4.18: Example of LAD parametric profiles for trees, 10m high globe canopies with light canopy density, LAI 1 (left), mean canopy density LAI 3 (middle) and high canopy density LAI 5 (right)

	Scientific Name	Popular Name	Height	Diameter	Method	Author	Year	City	Latitude	Summer 1-3		A
										Attenuation	LAI	Attenua
1	*Jacaranda mimosaefolia*	Jacarandá	10.00	8.00	1	Weingartner	1994	Porto Alegre	30S	95.7	6.44	-
2	*Tipuana Tipu*	Tipuana	15.00	18.00	1	Weingartner	1994	Porto Alegre	30S	95.4	6.30	-
3	*Delonix regia*	Flamboyant	8.00	10.00	1	Pietrobon	1999	Maringá	23S	95.4	6.29	92.0
4	*Tabebuia crysotricha*	Ipê Amarelo	6.00	6.00	1	Pietrobon	1999	Maringá	23S	83.9	3.86	48.3
5	*Tebebuia impetiginosa*	Ipê Roxo	12.00	8.00	1	Pietrobon	1999	Maringá	23S	84.2	3.89	48.4
6	*Caesalpinia peltophoroides*	Sibipiruna	12.00	7.00	1	Pietrobon	1999	Maringá	23S	89.9	4.77	85.9
7	*Hymenaea courbaril*	Jatobá	15.00	23.00	3 & 4	Bueno	1998	Campinas	22S	87.2	4.30	-
8	*Cassia fistula*	Chuva de Ouro	7.00	7.00	3 & 4	Bueno	1998	Campinas	22S	88.4	4.50	-
9	*Micheliia champacca*	Magnolia	9.00	8.00	3 & 4	Bueno	1998	Campinas	22S	82.4	3.68	-
10	*Tebebuia impetiginosa*	Ipê Roxo	11.00	10.00	3 & 4	Bueno	1998	Campinas	22S	78.5	3.29	73.8
11	*Caesalpinia peltophoroides*	Sibipiruna	8.00	6.00	3 & 4	Bueno	1998	Campinas	22S	-	-	88.5
12	*Fícus pandurata*	Figueira Branca	-	-	1 & 3	Pietrobon	1999	Maringá	23S	77.0	3.16	-
13	*Magnolia grandiflora*	Magnólia	-	-	1 & 3	Pietrobon	1999	Maringá	23S	85.3	4.03	-
14	*Tipuana tipu*	Tipuana	-	-	1 & 3	Pietrobon	1999	Maringá	23S	80.4	3.47	-
15	*Cedrela fissilis*	Cedro	-	-	1 & 3	Pietrobon	2000	Maringá	23S	84.9	3.98	-
16	*Senna Spectabilis*	Cassia Carnaval	8.50	9.00	3 & 4	Bueno	2003	Campinas	22S	-	-	90.4
17	*Schinus molle*	Aroreira Salsa	4.30	6.10	3 & 4	Bueno	2003	Campinas	22S	-	-	71.3
18	*Bauhinia forficata*	Pata de Vaca	8.00	8.10	3 & 4	Bueno	2003	Campinas	22S	-	-	84.8
19	*Clitoria racemosa*	Sombreiro	12.00	16.80	3 & 4	Bueno	2003	Campinas	22S	78.8	3.32	64.7
20	*Cingingium jambolana*	Jambolão	10.00	12.20	3 & 4	Bueno	2003	Campinas	22S	-		92.8
21	*Cedrela fissilis*	Cedro-rosa	7.60	7.80	3 & 4	Bueno	2003	Campinas	22S	-	-	46.4
22	*Ficus Benjamina*	Ficus	3.10	2.10	3 & 4	Bueno	2003	Campinas	22S	-	-	86.3
23	*Holocalyx balansae*	Alecrim de Caminas	8.10	7.80	2	Spangenberg	2007	São Paulo	23S	-	-	-
24	*Ligustrumlucidum*	Alfeneiro	8.10	10.70	2	Spangenberg	2007	São Paulo	23S	-	-	-
25	*Jacaranda mimosaefolia*	Jacarandá	10.30	9.80	2	Spangenberg	2007	São Paulo	23S	-	-	-
26	*Caesalpinia ferrea var. leiostachya*	Pau Ferro	9.70	12.40	2	Spangenberg	2007	São Paulo	23S	-	-	-
27	*Tibouchina granulosa*	Quaresmeira	6.60	8.00	2	Spangenberg	2007	São Paulo	23S	-	-	-
28	*Caesalpinia peltophoroides*	Sibipiruna	8.40	13.00	2	Spangenberg	2007	São Paulo	23S	-	-	-
29	*Tipuana tipu*	Tipuana	13.70	15.80	2	Spangenberg	2007	São Paulo	23S	-	-	-

Table 4.2: Measurements of shading coefficients of isolated, individual and mature urban trees in São Paulo/ Brazil (mostly native of Atlantic Forest binome)

Sources

Mascaró, L. (1996) Ambiência Urbana - Urban environment 2nd edition p. 70/71
Bartholomei, C.L.B (1998) Estudo da Atenuação da radiação solar incidente por diferentes Espécies arbóreas pg. 69 (Master thesis Unicampi)
Pietrobon, C. E. (1999) Luz e Calor no ambiente construido escolar e o sombreamento arbóro: Conflito ou compromisso cam a conservação de energia Florianopolis, 1999, Doctor thesis at the Feder
Pietrobon, E.C.,Resende, A.S.,Gonzalez, M.F. (1999) Tecnologia apropriada para a determinação de transparência arbórea através da luminância e do tratamento computacional de imagens
Bartholomei, C.L.B (2003) Influência da vegetação no Conforto termico urbano e no ambiente constrído, p. 56ff (PhD thesis Unicampi)
Spangenberg, J., Johansson, E. and Shinzato, P. (2007) Experimental CD metod (see chapter 4.2.3, table 4.2)

Autumn 4-6		Winter 7-9		Spring 10-12	
tion	LAI	Attenuation	LAI	Attenuation	LAI
	-	77.5	3.20	86.3	4.17
	-	57.5	1.96	88.5	4.51
	5.22	81.8	3.62	83.9	3.86
	1.58	21.2	0.75	67.0	2.45
	1.58	23.8	0.82	57.67	1.97
	4.12	68.9	2.57	80.2	3.45
		-	-	-	-
		-	-	85.7	4.09
		-	-	-	-
	2.90	-	-	-	-
	4.51	-	-	-	-
		-	-	-	-
		-	-	-	-
		-	-	-	-
		-	-	-	-
	4.87	-	-	-	-
	2.73	74.7	2.97	-	-
	3.97	-	-	-	
	2.32	73.9	2.91	78.4	3.28
	5.43	-	-	92.8	5.43
	1.51	-	-	78.0	3.25
	4.17	-	-	-	
	-	-	-	76.5	3.10
	-	-	-	66.5	2.41
	-	-	-	48.5	1.58
	-	-	-	33.5	1.10
	-	-	-	59.5	2.04
	-	-	-	55.0	1.85
	-	-	-	88.2	4.44

al University of Santa Catarina

Key for Methods
1 - Hermipherical Photography (Gap Fraction)
2 - CD lateral Photography
3 - Pyranometer (long & shortwave)
4 - Radiometer
5 - Empirical formula

5. COST-BENEFIT APPROACH

The aim of the proceeding chapters was to better understand the complex mode of action of urban vegetation while the following try to estimate quantifications of the benefits as demanded by various authors (see chapter 1).

It seems that environmental services of urban vegetation are constantly either underestimated or highly overestimated by planners, occupants and decision makers. Therefore it is important to establish approximated local values, to estimate *quantum change* and to establish guidelines.

Attempts to establish values for urban trees can be traced back to the end of the 19th century due to necessity to claim compensation payments for damaged or felled tress in the United States. The calculations of these models were based on simple physical measures, such as size, age, trunk diameter at breast height DBH (at 1.3m) etc., which were applied as direct value indicators (Detzel *et. al.* 1993). Later quantitative and qualitative indicators were combined in empirical formulas to assess monetary values (Detzel *et. al.*, 1993, Silva *et. al.*, 2002).

Improved methods of measurements of the complex plant-soil-atmosphere interactions (see chapter 4 and Jones, 1992) led to the (improved but still approximated) quantification of environmental (and in some cases social) benefits of plants (and other natural resources) especially in the United States. Recently the scientific understanding of the environmental functions of plants allows numerical simulations[1] and more exact estimations (or prognostics) of environmental costs and benefits.

The issue of assigning monetary values to the results of environmental (or ecological) analysis emerged in the late 1980s with the field of *Ecological economics* (Martínez Alier, 2007), which proposes the internalization of external costs of damages and analyzes concepts of utility, efficiency, quality of life and cost-benefit through multi-criteria analysis as tools for a paradigm changing market approach.

For example, the *Stern Review on the Economics of Climate Change* (by Lord Stern of Brentford for the British government, 2006) alerted (not only) economists to the importance of assigning monetary values to measurements of protection (or loss of resources) and to incorporate the environmental aspect into economical considerations (on a global scale?).

But as Martínez Alier (2007) points out, it is crucial to understand the limitations of these concepts: In *Ecological Economics* the discussion about the immeasurability of (certain) benefits is fundamental and makes *Ecological economics* not a matter of value-free *'hard science'* (as some researchers intend to conceptualize).

It should be pointed out that economics is considered in general a social science and that the values assigned for of goods or services depend however on an overview of the scarcity (see Smith, 1776) of these resources or services. It was, for example, only possible to establish a global carbon market (in the *Protocol of Kyoto*) because science changed the view on the issue, while for other benefits of urban vegetation, like stormwater management, improved air quality or thermal comfort no *real markets* do exist yet, which is why these markets are called *virtual markets*.

The biggest challenge of environmental modeling is the (more complete) understanding, systemizing and modeling of natural systems including the interferences of and on human activities. Since the subsystems are highly dynamic (and transgress political boundaries[2]), the definition of the temporal and spatial boundaries of the models is important, but difficult and further limited by technological capacities, the complexity (and price) of the models.

Generally it is agreed that each tree as its own specific value (Silva, 2002), mainly depending on size, age and localization. Abbud (2008) points out that planting inadequate vegetation in inadequate places can make the vegetation become rather a problem than a solution.

A tree-by-tree approach is only possible if the urban forest structure is analyzed through detailed and time-consuming street tree inventories (see Detzel *et. al.*, 1993, Silva *et. al.*, 2002) because the strong qualitative and quantitative variations make generalizations like the determination of a *mean value per urban tree* difficult.

Several attempts have been undertaken to measure plant performances to estimate the environmental benefits and/ or to assign indicators and monetary values. Vester (1986) was among the first who measured and monetized environmental benefits of a single 100-year old urban bleech tree (*Fagus sylvatica*) in Germany in detail. In another Germany study Köhler and Schmidt (1997) - recognizing that noteworthy greening potentials are principally localized on the building surfaces (their façades and rooftops) - monitored the environmental benefits

[1] It can be assumed that these benefits were appreciated tacitly for centuries (if not millennia) in vernacular communities.
[2] In fact some of the worst environmental degradation we face today occurs at scales that transcend political boundaries (American Forests, 2002)

of (non-tree) urban vegetation during twelve years in Berlin.

Subsequently in the United States extensive research on impacts of urban vegetation has been carried out from the 1990s on, mainly by urban foresters Nowak, McPherson and others, for example in Chicago 1994 and 1999, in Modesto in 2002, in Brooklyn, New York in 2005 and comparatively in five U.S. cities (Fort Collins, Cheyenne, Bismarck, Berkeley and Glendale) also in 2005. These studies are seeking for a valorization of urban vegetation mainly based on the quantification of environmental benefits applying representative strata inventories (predominant species/ biodiversity, health, distribution etc.) measurements and environmental modeling.

In the United States the cost-benefit analysis has proved to be a powerful instrument to estimate a monetary relation between the costs/ risks and the benefits of urban vegetation, to support public policies and (in the past) to invalidate prejudices against the eventual political motivation of the protagonists of such “green” urban development.

In Brazil, Detzel *et. al.* (1993) carried out a monetary evaluation of individual street trees in Maringá, in the State of Paraná/ Brazil developing empirical indicators based on two methods developed in the United States, which assign US$ 21 and US$ 27 respectively per square inch (6.45 cm²) bole intersection. The method assigns a value for each tree is based on age, specie, condition and localization in urban context varies between US$ 59.40 (for a one year old tree) to US$ 6,851.29 per tree (for trees above 50 years of age).

Silva *et. al.* (2002) developed another database for inventory system evaluation and management for urban street trees in the town of Jaboticabal (São Paulo State), which is like Detzel *et al.* (1993) based on early American models. For individual tree value calculation the inventory analyzes 28 parameters concerning dimensions, location, biology and interferences with infrastructure. The values for the rarest tree individuals are highlighted and range between R$ 71.005,66 to R$ 711.609,46 per tree.

	COSTS	Direct	Indirect	Estimated	Impact	Author (example)
MAINENANCE	**Planning and Administration**	x		x	+++	McPherson *et. al.* 2005
	Planting	x		x	+++	McPherson *et. al.* 2005
	Pruning, removal, disposal	x		x	+++	McPherson *et. al.* 2005
	Irrigation	x		(x)	+	McPherson *et. al.* 2005
	Litterfall		x		+	McPherson et. *al.* 2005, Gouvêa 2002
	Infrastructure/ Roots/ Canopy		x	(x)	+++	McPherson et. al. 2005, Velasco 2003
	Carbon Emissions for Maintanance		x		+	McPherson *et al.* 1994a, 1998
	Storm Damages & Accidents		x		+	Gouvêa 2002, PNUMA 2004
ENVIR	Decreased Dispersion of Pollutants		x		+	Santos *et. al.* 2004, Bruse *et. al.* 1999
	Winter Thermal Discomfort	x			+	Alucci 2006
	Building Moisture Intrusion		x		+	Lawson and O'Callaghan (1995)
	Decresed Daylight Levels		x		+	Mascaró 2005

	BENEFITS	Direct	Indirect	Simulated	Impact	Author (example)
ENVIRONMENTAL	**Summer Thermal Comfort**	x		x	+++	Spangenberg 2004, Ali-Toudert 2005
	Energy Efficiency	x		x	++	Akbari and Taha 1992, Velasco 2007
	Stormwater Management		x	x	+++	Ong 2003, Pauliet and Duhme, 2000
	Water and Soil Quality		x	x	++	Sanders 1994, Xiao *et. al.* 1998
	Increased Air Quality		x	x	++	Smith 1990, Von Stulpnagel *et. al.* 1990
	Carbon Sequestration		x	x	+	Jo and McPherson 2001
	Biodiversity and Wildlife Habitat	x			++	DeGraaf 1985, Ong 2003
	Sound and Vision Barrier	x			+	Long-Sheng *et. al.* 1993, Bistafa 2006
SOCIAL	Environmental Justice and Equity		x		++	Martínez-Alier 2007, Köckler 2007
	Fruits, Wood, medical substances	x			++	FAO 1999
	Green Jobs		x		++	UNCED 1992
	Urban Identity and Beauty	x			++	Robba and Macedo 2002
	Property Increase	x			++	Anderson 1988, Escobedo *et. al.* 2006
	Physical and Psychological Health		x		++	Grahn and Stigsdotter 2003
	Recreation	x			++	Morancho 2003

Table 5.1: Overview shortlist of costs and benefits, indication whether estimated or simulated and empirical estimate of importance of the impact on the cost/ benefit ratio

5.1 Overview for Estimations of Cost-Benefit Analysis

The following resume attempts to give a comprehensive overview (e.g for the elaboration of check lists), showing the complexity of the issue of urban vegetation. The price groups for tree maintenance proposed by McPherson *et. al.* 2005 were adapted and indirect costs (due to technical problems) derived from various expert interviews carried out with specialists of the SVMA of São Paulo. The benefit groups were derived from literature research (various authors).

Direct and indirect Benefits

Direct benefits are local, more certain and consequently more appreciated than indirect benefits. Local, direct benefits of vegetation are immediate benefits to buildings and properties (Akbari, 2001) like shade, thermal comfort, energy conservation, but also highly subjective benefits like aesthetics/ beauty, recreation and *hedonic* satisfaction (Mota, 2006). Further the direct use value describes the use of parts of the environmental resource, its raw material, e.g. wood, medical extracts and fruits. Direct benefits include also benefits generated on private property generated by both public and private vegetation.

Indirect benefits in contrast are regional, citywide or even global benefits, less certain and consequently less appreciated than direct benefits. Indirect benefits of urban vegetation especially in predominantly hot locations are linked to urban development, the mitigation of the urban heat island (thus indirectly thermal comfort and energy efficiency but also to ecological functions, biodiversity, hydrological resources, air quality etc.

The direct and indirect cost and benefit classes of the overview table below were derived from literature research (mainly McPherson *et. al.* 2005 and other sources indicated) and general observations which adapt the concepts to a tropical urban forest. It resumes the complex, sometimes beneficial and sometimes conflictive relations between urban vegetation and the other mostly technical urban infrastructures (like roads, and sideways pavements, wires and ducts). The list classifies environmental and social benefits, as well as maintenance, and environmental drawbacks (indirect costs).

The following section gives short comments on the direct and indirect costs for planting, maintenance and drawbacks (in 5.2) and of social and environmental benefits (in 5.3). The indicated authors are (as in table 5.1) preferably, local example authors. Of special interest are the environmental benefits summarized shortly in 5.3.1 because these will be analyzed (and modeled or estimated respectively) in more detail in chapter 6.

5.2 Costs

5.2.1 Planting and Maintenance

- **Planning and Administration** (McPherson *et. al.* 2005)

  McPherson *et. al.* (2005) remind that administration costs are often the highest costs of urban street trees/ the urban forest (including all administrative, planning, research, educational etc. activities). In São Paulo administration is divided by 32 sub-municipalities and supervised by the SVMA, while practice of planting and maintenance services mostly are awarded to public sector contracts.

  Various plans and public policies for urban greening exist in São Paulo and a tree inventory (SIGAL) is experimental phase. An improved revision and planning of the urban landscape, a more evenly distributed greening of public spaces as well as the strategic positioning of species according to their leaf density, growths etc. of vegetation would are necessary to improve the quality and to maximize benefits of the urban vegetation.

- **Planting** (McPherson *et. al.* 2005)

  The planting work in São Paulo is executed mostly by third party firms, but initiated by the sub-municipalities of each district and supervised by the SVMA. Since planting is also allowed without consulting the SVMA, the secretary published graphic material to indicate best practice, legislation, practical planting questions like indications of adequate species, planting on narrow sidewalks, below electric wires etc. (SVMA, 2005). However, whatever citizen has the right to order an urban tree in front of their house from the SVMA.

- **Pruning, removal, disposal** (Velasco, 2003)

  The pruning, removal and disposal work in São Paulo is mostly executed by three part firms, but in special cases (especially windbreak and case, linked to the electric wires, the electricity supplier *Eletropaulo,* as well as the fire brigade, are officially permitted to execute this work. According to *Eletropaulo*[3] fatal accidents, close wires to, caused by unprofessional pruning occurs.

- **Irrigation**

  The need of watering plants is rarely necessary in São Paulo. During most of the time of the year the generous rain gauges, of the hot and humid climate overcomes

[3] http://www.eletropaulo.com.br <access on 27th of June 2009>

evapotranspiration rates, so that water stress of plants (urban trees) rarely occurs. However during the aforementioned dry winters the need for irrigation becomes eventually necessary (due to limited storage) when water stress is too high to guarantee the survival of the plants.

- **Litterfall** (Gouvêa , 2002)

  Since urban trees in São Paulo are mostly evergreen or semi-deciduous accumulated litterfall (like during the autumn in temperate climates) does not occur but taller leafs sometime cause blockage of drainage pits (especially in combination with garbage and street waste) and thus (indirectly) contribute to inundations leading to (increased costs) for regular urban cleaning (see Gouvêa , 2002)

- **Infrastructure and Liability** (Velasco, 2003)

  The integration of street trees with the urban infrastructures (pavements, sewers, electricity, telephone, internet, cable TV, gas) is the biggest obstacle and challenge in many cities. In São Paulo there are especially conflicts of branches with aerial electricity wires and of roots with sidewalks and subterranean sewers and cables. Many trees planted in São Paulo (like *ficus benjamini*) are species with superficial and aggressive roots which destroy sidewalks and road pavements.

Fig. 5.1: Urban tree used as a shelter place (left) and single trees and green areas are abused to dump litter (right) (Photos by the author)

The crowns, aside from interferences with wires often do not warranted *structural clearances* for trucks and busses, due to ignored pruning needs of street trees with high-crown bases. The interference of views like obstruction of traffic signs, nocturnal street lighting etc. can further cause technical problems. The solutions of the aforementioned problems depend mainly on the planting, planting of the indicated species, vermin control and other sustained maintenances.

- **Carbon Emissions for Maintenance** (Nowak and Rowntree, 1991)

A drawback with neutralizing Carbon emission with urban trees is that tree maintenance equipment such as chain saws, chippers and backhoes emit carbon into the atmosphere.

In studies conducted by Dr. David Nowak and Dr. Greg McPherson of the U.S. Forest Service, they have suggested that if urban trees are properly maintained during their lifespan, the carbon costs outweigh the benefits. Carbon released from maintenance equipment and from decaying or dying trees could conceivably cause a carbon benefit deficit if it exceeds in volume the amount sequestered by trees.

Ong (2003) reports that certain plants also emit CO_2 and other gases (biogenic) emissions, on the other hand it has also been suggested that nocturnal street lighting could stimulate photosynthesis even at night. Additional research on metabolism for local species in urban conditions is recommended.

- **Storm Damages and Accidents** (PNUMA, 2004)

  The São Paulo Geocities Report (PNUMA, 2004, p. 109) contains statistical information about (sometimes fatal) accidents and damage of property which occur through wind breakage which occurs especially during torrential stormwater events during the summer, when it is not recommended to frequent the public space and to rather look for shelter. Storm damage is often caused when street trees are in unhealthy conditions (e.g. due to vermin) but also through the canalization of the wind in street canyons and increased wind-speeds (squalls). However the mitigation of damages highly depends on maintenance.

5.2.2 Indirect Costs and Drawbacks

- **Decreased Dispersion of Pollutants** (Oke 1987, Bruse 1999, Santos 2004).

  The roughness of permeable tree crowns leads to increased turbulence and so-called lee-eddies within and towards the leeward side the crowns, which decreases comfort-supporting ventilation. Further it can lead to chocking, so that airborne pollutants circulate and remain trapped, instead of being dispersed in the upper atmospheric layers. This phenomenon can occur especially along tree-lined bus corridors and avenues (see Santos, 2004, Oke, 1982, Bruse, 1999).

  Robba & Macedo (2002) point out, that the open spaces in hot cities especially in very dense (verticalized) urban areas are necessary to permit both sufficient isolation penetration (daylight) and air circulation, to facilitate the diffusion of pollutants.

- **Decreased Daylight Levels** (Pietrobon, 1999)

  Tree crowns decrease the heat/ cooling load by shading (low rise or not greened high-rise) buildings during the summer (which has a direct, positive effect on energy bills in hot climates, due to decreased energy costs) on the one hand, but on the other e.g. evergreen tree canopies do also decrease day-lighting levels (and thus energy costs and inefficiency) in lower stories, especially during the winter, when the solar path is low. Very dense and low leaf-albedo crowns (e.g. Ficus) decrease daylight factors and thus decrease natural lighting in the surrounding indoor spaces increasing operation time and costs for artificial lighting (Pietbon, 1999).

- **Winter Thermal Discomfort** (Alucci, 2006)

  Aside from the desired tree shade in during the summer during the winter tree shade can additionally lead increased cold stress within limited time-frames. This example shows that benefits of trees may at certain times of the year also become drawbacks, if not properly planned.

- **Building moisture intrusion** (Lawson and O'Callaghan, 1995)

  Shade and decreased direct solar radiation can lead to and increased humidity and moisture intrusion when buildings (especially near the ground floor) are not drying out which again can lead to mould fungus, weathering and spontaneous vegetation on buildings surfaces (see fig. 3.29)

- Safety

  Due to the morphological transformation of the space due to especially dense vegetation covers tree lined streets are sometimes be perceived as more dangerous due to decreased daylight levels and at night, especially in streets were street lighting is positioned above the canopies.

  Like in many cities world-wide green spaces are also in São Paulo often places of drug abuse and prostitution (e.g. Parque da Luz, were measurements and interviews were carried out in 2006), which is also the reasons why urban parks in São Paulo are fenced and closed at night. Some interviewees stated that they fear bandits hiding in trees crowns. It was also observed that places below street trees in São Paulo are often abused as litter dump (fly-tipping) and that tree shelter is occupied by homeless people.

5.3 Benefits

5.3.1 Environmental Benefits

The environmental benefits (or services from the human point of view) of urban vegetation can mainly be summarized as an improved equilibrium of the urban water and energy as well as carbon and nitrogen balance (and/or cycles) and thus the mitigation of the phenomenon of the urban climate and/or heat island balancing/ mitigating the meteorological factors (see chapter and figure 4.1).

- **Thermal Comfort (see 6.2.1)** (Spangenberg, 2004, Ali-Toudert, 2005, Johansson, 2006)

  Principally the shading properties leads to the mitigation of heat stress these properties lead principally during predominant hot periods to thermal comfort, but it should be remembered that the mitigation of climatic extremes due to vegetation during the summer may invert to disadvantages during the shorter tropical winters. Here strategic planting of deciduous trees can maximize benefits.

  The trees contribute to the shade on streets and squares and planted surfaces, e.g. flower beds or lawns (even though they do not provide overhead shade) do not absorb or irradiate as much heat as processed

[5] Humidification control: Especially in São Paulo's dry winter when air humidity reaches unhealthy values of less then 10% (with low air quality due to little gauges or no rain for longer periods) the increase of air humidity is urgently desired, but there may be little water availability for evaporation and irrigation required.

pavement, such as asphalt, concrete, cement (Robba and Macedo, 2002).

The main bioclimatic (regulation or control) mechanisms of vegetation are (according to McPherson et al. 1994a, Akbari et. al. 2001):

Shading Keywords: Absorption, transmission and multiple reflection of solar radiation | diffuse light | Blocking of heat (and light) | Keeping surrounding surfaces of urban construction materials cool | during most of the time increase of thermal comfort and energy conservation.

Evapotranspirational cooling and lower air temperatures Keywords: Cool leaf surfaces | humidification of air | lower set point for air conditioning and less energy consumption for cooling | leading to formation of clouds)[5]

Secondary, indirect climatic control benefits are:

Windbreak Keywords: Turbulence | loss of kinetic energy | wind chill | equilibration of wind-speeds | increased thermal comfort in the winter

Carbon Sequestration Keywords: Decreasing global levels of greenhouse gases | Protocol of Kyoto | Growth Rates | Biomass and Wood production | Carbon Storage

Fig. 5.2: Sunflecking due to shading (in Araraquara-SP) (above) and Evapotranspirational cooling (in Paúba-SP) as principal atmospheric cooling elements (Photos by the author)

- **Energy efficiency (see 6.2.2)** (Akbari & Taha 1998, McPherson 1994, Ali-Toudert 2005)

  Buildings located closely to or below tree canopies benefit from indoor thermal comfort and (potentially) decreased energy use for cooling buildings due to lower set points of air conditionings. Indirectly the carbon which would have been emitted for the energy production is additionally avoided.

- **Stormwater Management (see 6.3.1)** (Sanders 1984, Xiao *et. al.* 1998).

  Vegetation retains rainwater on leafs, acting like a sponge, slowing runoff. Thus they contribute to flood and soil erosion control, improved water and soil quality e.g. the protection and appreciation of natural resources, of waterways, lakes and reservoirs against contamination and pollution (Robba and Macedo, 2003). The unsealed soils associated to plants lead to a further improvement by draining water through permeable surfaces that absorb part of the water, filter it and reduce the speed of its flow. Further vegetation acts as medium to trap water inside soil and plant and to evaporate it over long periods of time.

- **Improved air quality (see 6.3.2)** (Smith 1990, Nowak 1994a, Klaus *et el.* 1998)

  By absorbing and filtering out nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) through their leaves, urban trees perform a vital air cleaning and particle absorption service that affects the well-being of urban dwellers and reduces respiratory diseases and thus costs of the health system (American Forests, 2002).

- **CO_2 Sequestration (see 6.3.3)** (Ong 2003)

  Plants are the only mean to sequester and store carbon (emitted in excess to the atmosphere) and to liberate oxygen inhaled by animals (and human beings), through the *photosynthesis* which gives them the status of *living machines*. Further plants produce wood, leafs and fruits which can serve as food and biomass (as a renewable energy resource and as well as a building material). Both have an important future prospective and trading *CO_2 credits* becomes an increasingly interesting market (especially in Brazil, as a tropical threshold country).

- **Biodiversity and Wildlife Habitat** (DeGraaf 1985, Ong 2003)

  The provision of urban wildlife habitat and biodiversity is according to Ong (2003) a difficult parameter. Especially in tropical counties plants can attract

Fig. 5.3: Democratic urban spaces in São Paulo's Ibirapuera Park, Praça da Paz on 1st of September 2007 (Photos by the author)

through fruits and flowers eventually undesired poisonous animals (like snakes) or transmitters of severe tropical diseases (like the *dengue fever* transmitting *Aedes aegypti* mosquito).

This is probably why *wilderness*, (*selvagem*) rather causes suspicion in tropical countries like Brazil than in the temperate regions of Europe and the North America were the perception might be more romantic and/ or bucolic.

However it can generally be assumed that an urban forest with a higher biodiversity could restore natural food-chains, allowing habitat of the natural predators of the aforementioned urban "pests", like cockroaches, rats, doves, scorpions, ants, termites and mosquitoes.

"While desirable, neither a minimum benchmark nor how an acceptable balance can be achieved manually have yet been identified yet. Nature, of course, establishes its own equilibrium and both enables and requires a high level of biodiversity to maintain this equilibrium. In the man-made landscape, it is not clear quantitatively how biodiversity benefits the human environment. On the whole, the recommendation is towards greater biodiversity and enabling a natural balance as much as possible. Connections between green patches are useful in helping animal migration but also increase the risk of infection and contamination" (Ong, 2003).

- **Sound (and Vision) Barrier** (Huang et. al 1992, Long-Sheng et. al 1993, Bistafa 2006)

Through their leaf mass and the multiple reflection of noise between the leafs vegetation acts (to a limited degree) as a noise buffer or sound barrier absorbing airborne sound. However the measurable noise buffering effect of vegetation is low but especially high frequencies can be influenced favorably through tree plantations. More important seems to be psychological protection effect of green which should not to be underestimated. The *out-of-sight-out-of-mind* effect created by vegetation against loud expressways and to avoid *visual pollution* was reported for example by Bistafa (2006).

"Tree plantings as noise barrier are an article of faith with many landscape professionals and their clients. In fact the cut noise significantly in terms of actual decibels, a band of planting at least 100 feet wide is required. These plantings must include both, dense scrubs and trees; trees alone are ineffective. Even in these widths and with appropriate species, a tree barrier can reduce sound only about 3 to 5 decibels per 100 feet. Any effect from smaller planted barriers is primarily out-of sight, out-of mind phenomenon – valuable in its own way, but not actually decreasing physical noise. Except on very large properties where a "noise forest" or extensive grading might be used, neither planting nor physical landscape construction offers particularly good possibilities for decreasing the actual noise itself. This leaves two options for the landscape professional: screening or making the perception of noise and lobbying for policies that prevent or decrease noise at its source. Make noise invisible" (Thompson and Soving 2000)

5.3.2 Social benefits

- **Environmental Justice and Equity**

Since the socio-environmental disparities in megacities in emerging countries, like São Paulo, are often harsh, an increased environmental equilibrium through broader public vegetation can help increasing public safety, decreasing contrasts and crime rates (Martinez-Alier 2007, Maathai 2006, Pedlowski 2002, Escobedo *et. al.* 2006).

Kuo, *et. al.,* (1998) found that the more trees and grass in the common spaces of inner-city neighbourhoods, the more those spaces are used by residents. The study also found that, compared to residents living near barren spaces, those closer to green spaces enjoy more social activities, have more visitors, know more of their neighbours, and have stronger feelings of belonging. In other words, relationships between neighbours are made stronger simply through the presence of vegetation.

In São Paulo especially large green areas and parks, like the aforementioned Ibirapuera Park, are the cities most *democratic* urban spaces, where all social strata meet in public spaces, especially on weekends and where conflicts and contrasts apparently become almost invisible[6]. This aspect seems to one of the most important social benefits of green in megacities in threshold and developing countries but the cities green areas are difficult to reach and not well-integrated with the public transport system.

The amenities of living in well-greened neighborhoods in São Paulo close to or within the central region are restricted to the former *Garden Neighbourhoods*, the Morumbi district and a few others mostly located in the south-west vector. In the peripheries close to the edges of more natural landscapes, green areas are more accessible but pressure on space in irregular settlements, although often peripherical, is so high that these areas rapidly become sparse of vegetation and represent clear boundaries between the settlement and the forest.

- Green Jobs

For example the Agenda 21 (composed in Rio de Janeiro in 1992) mentions the need to create employments which foster more sustainable cities. *Green Jobs* are for example employees which work with tree planting, maintenance and to improve the health and safety of the urban forest. Recently some projects intend to employ e.g. local *tree-godfathers* in neighbourhoods on a voluntary basis.

[6] Similar phenomena are reported, especially from Rio de Janeiros beaches for example in Vaz, Knierbein and Welch Guerra (2006)
[7] In his presentation in São Paulo on 2nd of March 2009 on São Paulo

- **Identity and Beauty** (Robba and Macedo 2003)

  Although nature's fragments inside the metropolis are often perceived as left-overs of the urbanization process, strange, alienated and even "foreign objects" they remain important objects in the urban landscape, represent *Nature* and/or every-day *Poetry* (as Prof. Christian Werthmann named it)[7]. Robba and Macedo (2003) mention e.g. the blue flowers of the Jacarandá tree, or the red, white and yellow flowered Ipês, as symbols of urban identity and beauty in Brazil.

  "Open spaces bear symbolical importance as well because they become referential and scenic objects in the city landscape, fulfilling an important role in the identity of the neighborhood or streets. We have all used "the square" or the "big tree in bloom" near our house as a reference to indicate the way or give directions. They are objects of our urban embellishment, recovering the image of nature in the city. Green and landscaped spaces are progressively associated with an oasis amid massive urbanization" Robba and Macedo, 2003

- **Property increase** (Escobedo *et. al.* 2006, Anderson and Cordell 1988, Morancho 2002)

  In cities with great socio-economical contrast like São Paulo vegetation cover can be indicator marginality principally in the peripheries. However in formal inner-city neighbourhoods it tends to increases property (and housing) value. Some cost-benefit models like the UFORE and STRATUM models (USDA, 2006) consider the increased value of the property due to tall trees applying an empirical formula derived in the United States.

  Anderson and Coredell (1988) found that each large front-yard tree was associated with 0.88% increased in sales price in the U.S. According to estimates by Morancho (2002), in Spain each 100 meters further away from a green area means a drop of approximately 1,800 Euros, of median housing price. In São Paulo, Giannasi (2007) reported that the values of apartments in residential towers with views on Ibirapuera Park are worth double than those without views on the extensive inner-city green area.

  However, it seems as if the urban residents perception of urban green in São Paulo was changing recently, as various release handouts for residential real estate enterprises which offer views on parks and forests (and/ or are well greened themselves) collected between 2007 and 2009 illustrate.

- Urban Agriculture

  An increasingly researched and proposed form of urban vegetation in the course of sustainability is crop growing (also e.g. in combination with small livestock breeding). Local food production is a retro-innovation (and was common in the past) and food self sufficiency is an interesting option to exploit urban resources and to increase quality of life especially though more independency of the underprivileged urban population.

  Although unimportant yet in São Paulo, in Brazil various projects exist for example in Sete Lagoas in the State of Minas Gerais (Lutterbach, 2007) were food is being cultivated on urban areas which were unutilized in the past. In São Paulo harvesting the literally "low hanging fruits" of fructiferous street trees is a quite common activity, while the fruits can, if not harvested be a problem.

  However, especially the roofs of buildings as well as abandoned inner-city areas (brownfields) could in the future be interesting options to lay out *community gardens* because the synergetic effect which foster local food production, decrease transport cost, air pollution, increase independency, energy efficiency, stormwater retention etc. influence urban sustainability positively in many ways.

- **Physical and psychological Health** (Ulrich *et. al.* 1991, Schroeder and Lewis, 1991)

  Various authors report the decrease of stress-related illnesses due to *contact with nature*). For example Taylor, *et. al.* (2001) found that symptoms of children with Attention Deficit Disorder (ADD) are relieved after contact with nature. The greener the setting, the more the relief was reported. By comparison, activities indoors such as watching TV or outdoors in paved, non-green areas leave ADD children functioning worse.

  Robba and Macedo (2003) mention e.g. that the solar protection of tree canopies could decrease skin cancer, due to decreased ultraviolet solar radiation in tree shaded public spaces. However, since natural landscapes in megacities like São Paulo are in many locations distant and/ or difficult and time and money consuming to reach, the contact of city-dwellers with the nature is often limited to inner city urban vegetation (street trees and parks).

- **Recreation** (Morancho, 2003).

  Various authors mention the importance of urban green for recreation, either in private gardens (see property increase) or in parks and other green areas (see Environmental Justice and Equity) *Hedonic* approaches, which regard "pleasure is the highest good", recognize urban vegetation as something "right" because it causes pleasure (see Morancho, 2003).

6. ENVIRONMENTAL MODELLING AND ESTIMATIONS

After looking into the history of massive urban land-use change and consequently the decrease of the vegetation cover in the São Paulo region due to a rapid urbanization process during the 20th century (chapter 2), the climate regulating functions of urban vegetation and metrics (and their tempo-spatial variations at macro-scale and at micro-scale) for modelling (chapter 3), the approximation on the cost-benefit relation (chapter 5) *modelling of the environmental benefits* of *urban vegetation* became aim of this work and is described in the following chapters.

Since the social benefits (summarized in 5.3.2) are even more difficult to be modeled and/or estimated/ valued, they will be ignored in this part which deals with the modelling and the quantification of only the environmental benefits.

Generally the environmental models are here applied as a methodology to estimate the relations between input parameters (such as leaf area or vegetation cover) and the feedback of the atmosphere-soil system e.g. climate (output). Modelling - although signifying reduction, construction and abstraction - is the only feasible method to estimate environmental benefits of urban vegetation for a metropolis of the magnitude of São Paulo.

Since no comprehensive model exists yet to simulate all important environmental benefits, different models with different degrees of complexity had to be applied here. They range from detailed, dynamic (local, micro-scale), static (regional scale) to a simple empirical models to estimate the benefit per tree on energy consumption (McPherson *et. al.,* 2005).

Another advantage of models is that they allow explications, prognostics and comparisons of various scenarios that include for example seasonal changes and growth of the vegetation (density, size, etc.).

6.1 Approaches and Models

Among the various models analyzed for this study two scientific approaches to model city-wide (and local) environmental benefits of urban vegetation (and to optionally assign monetary values for a cost/benefit relation) were separated:

- **Analyzing detailed Inventories of the Urban Forest Structure** (see USDA, 2006, Detzel *et. al.* 1993 and Silva *et. al.* 2002). This approach relies on citywide, randomly chosen, representative strata (samples) of the most abundant/ typical species, distribution, health state etc. within the municipal boundaries and subsequent extrapolations, which intend to reflect the spatial structure and conditions of the whole urban forest.

The tools STRATUM (acronym for Street Tree Resource Analysis Tool for Urban Foresters) and UFORE[1] (acronym for Urban Forest Effects), (USDA, 2006), applied e.g. by McPherson *et al.* (2005) in five U.S cities, follow this approach and was analyzed for this case study. The tools estimate annual environmental benefits such as energy conservation, air quality improvement, CO_2 reduction, stormwater control and property value increase as a result of urban trees.

Tree-by-tree approaches are only possible if the urban forest structure is analyzed through detailed and time-consuming street tree inventories (see Detzel et. al., 1993 and Silva et. al., 2002 for Brazilian examples applied in small cities) because the strong qualitative and quantitative variations make generalizations like the determination of a *mean value per urban tree* difficult.

While Silva *et. al.* (2002) recommended the sampling of 30-70 randomly selected trees (eight measures per tree) representing the most abundant species to analyze the urban forest structure in smaller Brazilian municipalities, the USDA indicates sample inventories of 3.5% of all urban trees to obtain representative strata.

[1] http://www.itreetools.org/stratum.shtm <access on 27th of June 2009>

Reminding the 1.5 million urban trees estimated by Gregório (2006), 52,500 trees would have to be measured in São Paulo. Assuming 4 minutes per tree this would result in São Paulo in 3,500 hours of sampling work by specialists (and trained volunteers). Further the very heterogeneous distribution or urban trees in São Paulo's urban fabric (see chapter 3.2.2) complicates the definition of sampling areas. Therefore here the following land-use based and more time and cost efficient the following method was given preference.

- **Analyzing Aerial Photos and Classifications** (American Forests, 2002), allows a so-called *Rapid Ecosystem Analysis* which estimates of environmental benefits of the whole urban forest from calculations based on urban vegetation cover classifications. These classifications are derived from regional *remote sensing,* satellite, or low altitude flight images which offer different degrees of detail due to resolution, pixel size etc.

  The combination of detailed inventories of the urban forest structure using vegetation cover *remote sensing* and *ground-truthing* or check surveys promises the best results but is also most time and cost consuming. Further such citywide investigation can be adapted, expanded and supported by additional detailed local case studies (inventories) e.g. on energy conservation and/ or increased thermal comfort applying micro-climate simulations for parametric typical urban tissues as in this case.

Due to limitations of the existing computer models it is important to define the models and their temporal and spatial boundaries (model domain and time step) and thus the scales since the benefits generated by urban vegetation range from very local scale (thermal comfort due to tree shade), to regional (improved stormwater management and air, water, soil quality) and global (sequestration of carbon dioxide).

Since most of the models are developed and calibrated in countries of temperate climates they need to be adapted to the conditions tropical countries to allow reliable prognostics of benefits because tropical evergreens e.g. may provide greater benefits in urban settings than the deciduous trees of the temperate climates because of their round year foliage. Therefore it was recommended to verify the results in accordance with local conditions (e.g. through measurements).

The following the tools to assess, simulate and quantify benefits of urban vegetation applied in this work are presented. Due to the novelty and complexity (e.g. tempo-spatial climatic changes, variations of leaf density, growth etc.) of simulating environmental benefits of vegetation in tropical megacities certain limitations of a simplified but comprehensive approach must be accepted, limiting the results to estimations.

- **ENVI-met**[2] (Bruse, 1998)

  One of the main efforts of this work is to estimate the benefits of urban vegetation on thermal comfort and thus the quality of public spaces as well as the reciprocal relation with the energy consumption of surrounding buildings.

  The urban micro-climate ENVI-met model was chosen due to its sophisticated plant model. Due to its fluid dynamics approach, a drawback for this work is that annual balances are not feasible to conduct so that one typical summer day (19th of December 2006) has to be chosen for the study of benefits of thermal comfort. The model further had to be calibrated to the climatic conditions measured *in situ* (see Spangenberg *et. al* 2007).

  It was not possible to calibrate the daily courses of all climatic parameters of the measured climatic conditions (without *"forcing"* the model) but especially its capacity to simulate the locally highly varying parameter of *Mean Radiant Temperatures* (MRT) which is the key to estimate thermal comfort in different urban morphologies (e.g. with different greening ratios) on hot days (see Ali-Toudert 2005) is useful to better understand effects and tendencies of different spatial arrangements.

- **RAMS** (Pielke *et al.,* 1992)

  Since the regional climatic parameters which develop over larger scales could not be modeled appropriately with the microclimate model ENVI-met to calculate thermal comfort, air temperature and humidity were used from output data of city-wide simulations with RAMS (Regional Atmospheric Modelling System) for the same day carried out by Mariana Lino Gouveâ (Department of Atmospheric Sciences of the University of São Paulo) and used as input for the calculation of the *Temperature Equivalent Perceived* TEP (Monteiro, 2008).

- **Tensil** (Alucci, 2006)[3]

  The software Tensil 1.2 uses local and regional climatic data collected nationwide between 1961 and 1990 and gathered by The National Institute of Meteorology INMET[4]. The program simulates thermal comfort below overhead shading elements and was originally designed to estimate thermal comfort below canvas (tent roofs). Here a pre-version of URBCOM (to be published in 2010) which allows

[2] An overview of Urban Climate Models can be found on http://www.stadtklima.de/EN/E_2TOOLS.HTM <access on 27th of June 2009>
[3] http://www.usp.br/fau/ensino/arq_urbanismo/disciplinas/paginas/conforto.html <access on 27th of June 2009>

simulating the effects of tree canopies was used to estimate the periods of improved thermal comfort.

- **CITYgreen** (American Forests, 2004)

  CITYgreen is an analysis tool for ARCGIS (by ESRI) to estimate benefits of urban vegetation from land-use raster classification at regional and local scales. The analysis, also called *Rapid Ecosystem Analysis*, does not depend on individual tree inventories but analyses vegetation cover and type using regional remote sensing (satellite) or aerial (plane) imagery classified for land cover. According to the authors, "the strength of the software lies in its ability to translate the once-intangible benefits of trees into real dollar amounts that can be factored into policy makers' balance sheets". The model estimates annual stormwater retention, improvements of soil, water and air quality and CO_2 sequestering.

However, one of the main challenges of this study is, that the models are applied for the first time here in the context of a citywide study are yet not calibrated (and not completely reliable), to exactly predict the outcome of urban canopy change (and thus e.g. on climate change). The local context of a tropical megacity with sparse vegetation located in an emerging country makes further made it difficult to assign ranges of monetary values for benefits.

Therefore the results of this study should be taken rather as approximations and estimations (and not as definitive values) for the costs and benefits of urban vegetation and as an indication that it is worth considering environmental services from it.

A further limitation of this work is, that it analyses only the most important environmental benefits (see tab. 6.1). These are divided into the (more appreciated) direct benefits - which are interesting to planners, owners and occupants - and (less appreciated) indirect benefits, which should be recognized especially by decision-makers and politicians, because they can probably only be improved through environmental legislation or incentives.

6.2 Direct, local Benefits

It is reminded that the direct environmental benefits estimated here are local, more certain and consequently more appreciated than indirect benefits because they are immediate benefits to buildings and properties (Akbari *et. al.*, 2001). These benefits (like shade, thermal comfort, energy conservation) show especially very high spatial variations within the various morphologies of São Paulo's urban fabric which makes generalizations extremely difficult. Generally it can be resumed that the direct benefits of urban vegetation are higher in low-rise regions, (as long as high-rise buildings are not greened).

	Regional citywide	Local Neighbourhood
Thermal Comfort	RAMS	ENVImet/ RAMS/ Tensil
Energy Consumption		(Empirical approch)
Water Management	CITYgreen	
Soil & Water Quality	CITYgreen	
CO2 Sequestration	CITYgreen	
Air quality	CITYgreen	

Table 6.1: Overview of simulation tools applied and respective boundaries/ scales

6.2.1 Thermal Comfort

One of the main direct, environmental benefits of urban vegetation cover, especially in predominantly hot climates of low and mid (tropical and subtropical) latitudes is the improvement of the quality of the public space[5] due to the increase of thermal comfort[6] during considerable timeframes (see Ali-Toudert, 2003, Spangenberg 2004, Johansson 2006). In the light global heating and urban sustainability thermal comfort must be one of the main aims of the urban transformations.

Of all benefits accessing thermal comfort and energy efficiency is the most complex due to very strong temporal and especial variations. Therefore this studies uses simplifications (such as typical urban tissues and a typical summer day) to show tendencies and estimations. The attribution of a monetary value was solved applying a value derived from another research.

However the direct benefit of shade is economically widely underrated. Trees are often a crucial urban element to improve the thermal quality in constructed tropical environments. Periods of peak thermal discomfort occur (in tropical latitudes) mainly around (and principally after) noon time, in summer, when solar angles are highly inclined (zenithal on summer solstice).

During these time frames *overhead shading* becomes crucial for outdoor thermal comfort, because otherwise important building shade is deniable and because other horizontal shading elements are rare. The aspect of thermal comfort affects all users of public, open spaces like pedestrians, car drivers and (motor) cyclists.

The shading coefficient (or the ratio the between transmission and attenuation of solar radiation) of tree canopies (depending on leaf area density) is the most important indicator for local peak heat stress mitigation because direct solar radiation is the climatic

[4] www.inmet.gov.br <access on 27th of June 2009>
[5] According to Welch Guerra (2006) the public space can here be defined as an ensemble of streets, squares and parks that are, as a basic principle, publicly available, accessible and collective
[6] In German: thermische Behaglichkeit, in Portuguêse: conforto térmico. Since concepts, definitions and ranges greatly vary throughout literature it should be noted that mitigation of heat stress through shade might be a better description of this benefit of urban vegetation in tropical latitudes

parameter which mainly causes heat stress. The shading coefficient of trees (as *overhead shading elements)* is defined by leaf area index (or density respectively) (see chapter 4.2.3). The parameter will be coupled here with computational microclimate simulations to model and estimate the *perceived temperature*.

In the tropics, the outdoor thermal comfort conditions during daytime are often far above acceptable comfort standards due to intense solar radiation and high solar elevations (Ali-Toudert and Mayer, 2007; Johansson, 2006). Although the climatic conditions in São Paulo are relatively mild compared to winter climatic conditions in temperate heat stress is becoming a problem which decreases quality of life. Serious cold stress only occurs rarely, only during winter nights, cloudy winter days and transitional periods between night and day.

Individual adaptation devices to protect the body against the absorption of solar radiation are sunhats, (topees), reflective, light cloths, parasols, sunglasses (against glare) etc. In hot many places it is recommended today to stay indoors during the midday hours, traditionally the *siesta* in Spain.

Only horizontal, *overhead shading* elements such as building overhangs, pergolas and/ or trees can improve (or even guarantee) thermal comfort during these hours. Diffusion or shielding, the creation shade is crucial for the generation of thermal comfort.

Generally benefits of thermal comfort in public spaces are:

- Increased thermal quality of open public spaces, especially for pedestrians and cyclists, as well as for motorists leading to higher productivity. In São Paulo 30% of all travels are made by foot and the promotion of using bicycles is an important aim to turn transportation more sustainable (see *Pesquisa Origem-Destino* 1997 by Companhia do Metropolitano de São Paulo Metrô/ SP),

- Thermal comfort in open spaces leads indirectly to an increased energy efficiency of surrounding low-rise buildings and vehicles, which use ca. 30% less fuel, when air conditioning is turned off.

The parameters of urban climate (or urban heat island(s), see chapter 3.2.1, table 3.3) and those of vegetation (see 4.2) are closely linked to human thermal comfort (and have also reciprocally again influence the urban fauna and flora). Many studies link thermal comfort directly to ambient air temperatures, which does not exactly express the real comfort patters of outdoor spaces in the tropics, which are in fact driven by shading patterns, due to the strong and vertical solar radiation.

The following two Brazilian example studies indicate further benefits of thermal comfort using equilibrated air temperatures as indicators: Rivero (1985)

Fig. 6.1: Overhead shading elements aside from trees are pergolas, building overhangs (arcades), marquises, solar sails, canvases etc. Partially transmissive and movable device in courtyard in Seville/ Spain (Photos: Simmos Yannas)

found that comfort leads to decreased numbers of work accidents (operational security), increased work efficiency and human performance, around an ideal air temperatures of ca. 20ºC.

Mendonça (2002) analyzed correlations between monthly mean air temperature and homicide rates in ten Brazilian cities and found for São Paulo a correlation with $R^2 = 0.56$, indicating that thermal comfort (here also indicated by air temperature) may, during the temperate winter (or due to decreased urban temperatures) be correlated to decreased urban violence.

It should be pointed out that these investigations based only on the one mean meteorological parameter of air temperature must be evaluated critically because air temperature can be used only as an indicator since the radiation balance is more significant for thermal comfort.

6.2.1.1 Thermal Comfort Indices

Although thermal perception depends highly on the individual objectifying *thermal comfort* (or *heat stress* respectively) is possible by calculating the *human energy balance* (gains and losses of energy) and calibrate indices in combination with *surveys* with locally adapted persons. The empirical formulas can then predict thermal sensations for the majority of the population (up to 90%) and indicate more sustainable urban morphologies.

All indices are composites achieved by weighting the impact of the meteorological parameters. In open spaces comfort indices allow to calculate human biometeorological thermal comfort in the canyon air volume at near-surface height of usually at 1.1m to 1.50m above ground, which refers to the average height of a standing person's center of gravity in Europe (Matzarakis *et. al.* 1999).

The main variables to determine thermal comfort are

- **Microclimatic variables** (in order of importance)
  - Mean radiant temperature (MRT)
  - Air temperature (T_{air})
  - Air velocity (V_{air})
  - Air humidity (RH_{air})
- **Individual variables** (metabolism rate, clothing insulation and albedo)
- **Subjective perceptions** (the preference of thermal sensations, e.g. "Some like it hot")

Generally thermal comfort in open spaces is mainly influenced by (direct) solar radiation (increase of heat stredd) and of air movement (ventilation, decrease of heat stress) represent high variations especially (in tropical latitudes), while air temperature and humidity vary less and are more homogeneous in spatial terms.

In the following five indices to assess thermal comfort in the tropical outdoor environments analyzed are shortly outlined. Three of them (according to necessities of different models) will be

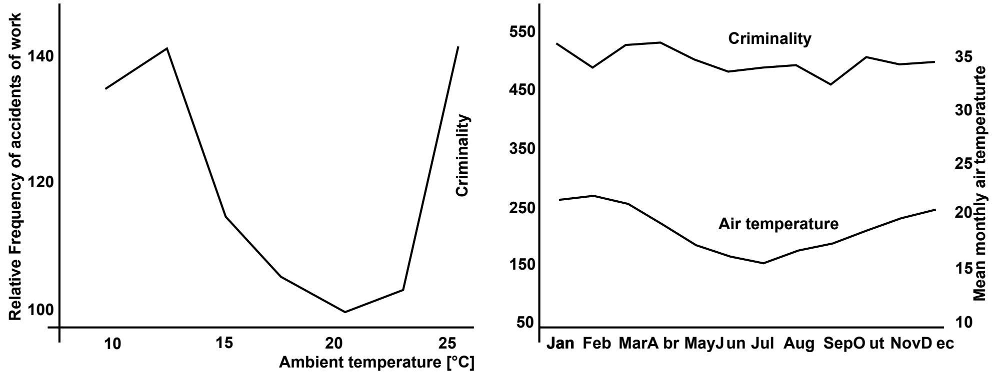


Fig. 6.2: Relative frequency of accidents related to air temperature, Riveiro, (1985) (left) Correlation between air temperature and urban criminality in São Paulo, analyzing mean air temperatures 1961-1991 and 1979-1995, Mendonça (2002) (right)

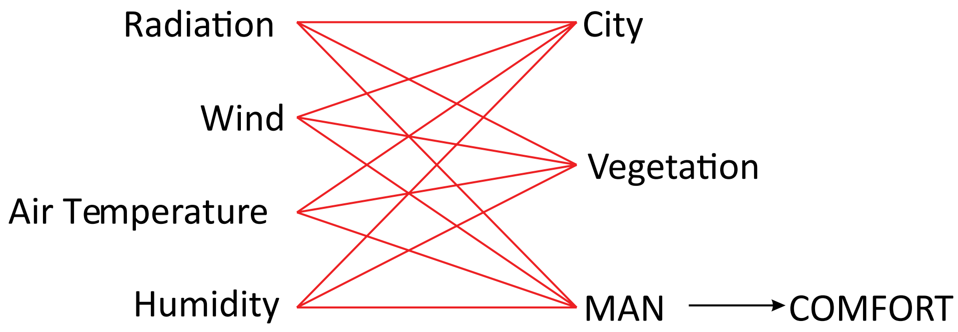
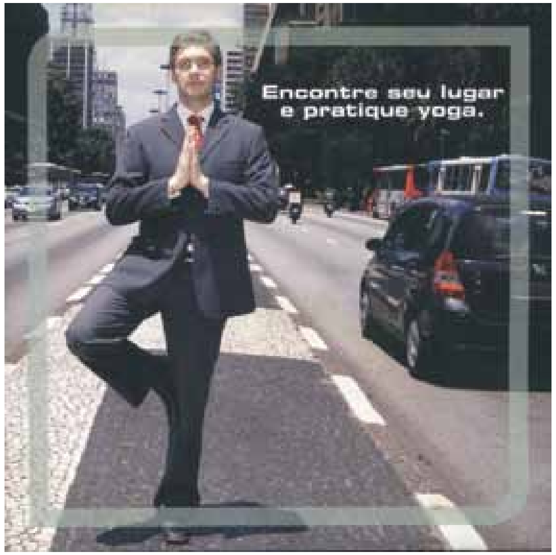


Fig. 6.3: Brainmap shows the complex interactions of microclimatic parameters and the urban environment necessary to be analyzed to assess thermal comfort in a simplified way

used as indicators to estimate thermal benefits of tree canopies (and urban typologies). A more complete list of calibrated of indices for São Paulo can be found in Monteiro and Alucci (2005).



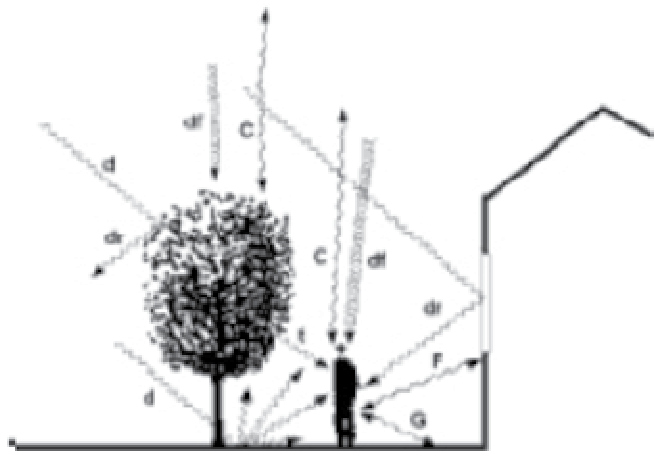


Fig 6.4: Meditating man on Paulista Avenue in São Paulo, picture to illustrate environmental and especially thermal discomfort (Advertisement 2006) (left) Scheme of impacts to calculate thermal comfort in urban situations near surface (right)

PMV - Predicted Mean Vote Index (Fanger, 1970)

According to Bruse the index was originally developed for indoor situations and subsequently adapted for outdoor climate by Jendritzky (1993, unpublished). PMV is still the base for ISO 7730 and ASHRAE standards. However various authors, like Grimme *et al.* (2003) and Spangenberg (2004) have pointed out that especially the cooling effect of air velocity is not calculated in an appropriate way in tropical situations.

PET - Physiologically Equivalent Temperature (Höppe, 1999)

The MEMI (Munich Energy Balance Model for Individuals) was developed for outdoor conditions and is fully described in the German VDI-Guidelines[7]. The approach calculates a temperature analogy, the perceived (or effective) temperatures (given, like e.g. air temperature, in °C).

A common tool to calculate the Physiologically Equivalent Temperature is *Rayman* (Matzarakis, *et. al* 2002). PET was calibrated by Monteiro and Alucci (2005) for São Paulo climatic conditions and occupants adaptation and is being calibrated by Katzschner (2007) for various global places. The neutral temperatures given for temperate climate in Kassel (Germany) are 15-22°C and for example 21-28°C for subtropical climate like Athens (Greece).

HL – Heat Load (Blazejczyk, 2002)

Blazejczyk (2002) also applies the MEMI (Man Environment heat exchange model, see Höppe 1998) but with a modified approach to take solar radiation into account. Because the concept of thermal comfort may be misleading Alucci and Monteiro (2007) also prefer the concept of Heat Load, proposed in this concept and applied in Tensil (Alucci, 2005).

dPET – Dynamic Physiologically Equivalent Temperature (Bruse, 2007)

In a state-of-art approach Bruse (2007) proposed multi-agent system for assessing dynamical urban thermal conditions using the indicator PET (see above). The climBot model is a plug-in model for ENVI-met (applied here) which takes the thermal short term history of the individuals moving in urban structures into account (heating and cooling of the human body, clothing, metabolism rate, etc).

TEP - Temperature of Equivalent Perceptive (Monteiro, 2008)

The indicator Temperature of Equivalent Perceptive (TEP) is the only locally calibrated indicator for climatic conditions in São Paulo yet and makes an analogy to air temperature like PET. The index is originally named *Temperatura efetiva percebida*. To calibrate the indicator Monteiro (2008) carried out surveys of more than 2000 individuals in three locations: open sky, overhead shading membrane and overhead shading tree on the campus of the University of São Paulo.

$$TEP=-3.777+0.4828* T_{Air} +0.5172* MRT +0.0802* RH_{Air} -2.322* V_{Air} \quad (4)$$

where

T_{Air} = Air Temperature in ºC
MRT = Mean Radiant Temperature in ºC
RH_{Air} = Relative Humidity of air in %
V_{Air} = Velocity of air (m/s)

[7] VDI 3787 Blatt 2 "Methoden zur human-biometeorologischen Bewertung von Klima und Lufthygiene für die Stadt- und Regionalplanung" Teil I: Klima.

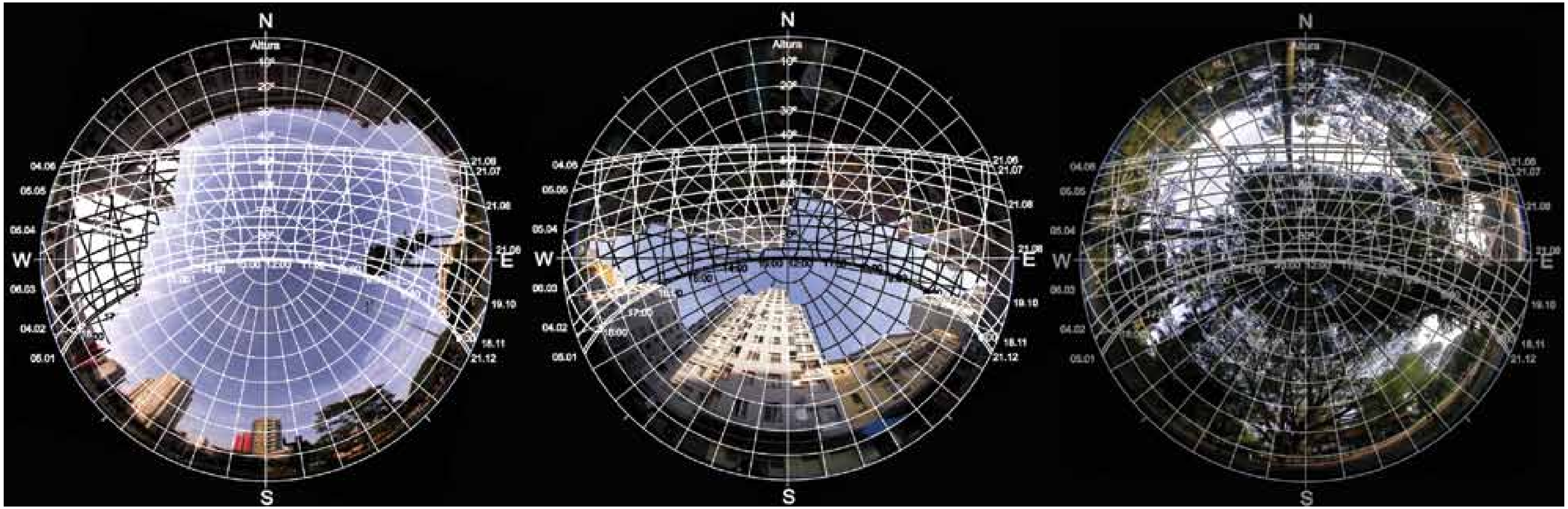


Figure 6.5: Hemispheric pictures of the sky view with fish eye lens for park (left), canyon (middle) and open square (right).

TEP in ºC	Key English	Key Portuguese
> 50.0	extremely hot	extremo calor
42.5 ~ 50.0	very hot	muito calor
34.9 ~ 42.4	hot	calor
27.3 ~ 34.8	slightly hot	pouco calor
25.4 ~ 27.2	very slightly hot	leve calor
21.5 ~ 25.3	neutral	neutralidade
19.6 ~ 21.4	very slightly cold	leve frio
12.0 ~ 19.5	slightly cold	pouco frio
4.4 ~ 11.9	cold	frio
4.3 ~ -3.2	very cold	muito frio
< - 3.2	extremely cold	extremo frio

Table 6.2: Interpretation ranges for Temperature of Equivalent Perceptive (TEP) by Monteiro 2008

A sensibility study of TEP showed that decreases of 1.94°C MRT, 2.07ºC of air temperature and 12.5% of humidity are necessary to lead to a decrease to an increased comfort of 1ºC TEP, as well as an increase of wind speed of 0.43 m/sec.

Since it was found that tree shade can reduce MRT by up to 16°C, while air temperature and humidity is difficult to decrease, and wind speed difficult to increase through the aerodynamic optimization of the urban structure. Thus shade is the most effective strategy to increase thermal comfort in predominantly hot cities.

6.2.1.2 Modelling Methods

On-site measurements and climate monitoring were carried out on 19th of December 2006 in the central area of São Paulo (Neighbourhood Luz). This day can be considered a typical hot summer day and was used as a base case for climate simulations. The main goal of these measurements was to create an initial database for air temperature, relative humidity, solar radiation, surface temperature, wind direction and wind speed for the summer period.

Three main typologies of urban spaces were defined for the measurements: a park, an open air square and an urban canyon. Three meteorological stations (Huger WM 918 and 968, as well as ELE MM900) were used to measure air temperature, humidity and wind speed simultaneously at 1.10m height at the three locations (see fig. 6.5). All measurements were recorded on data loggers every ten minutes between 7:00h and 19:00h local daylight saving/summer time.

On the square, additionally global solar radiation was measured with a pyranometer. Surface temperatures of various construction materials and natural surfaces were measured on the square using an infrared thermometer TFA 31.1108 (see fig. 4.9). During the intervals of the measurements interviews with pedestrians regarding their thermal comfort sensation and their opinion on benefits and problems with vegetation in the city were carried out.

Since is was not possible to simulate the additional local climate parameters to estimate the thermal comfort indicator of Perceived Effective Temperature (Monteiro 2008) with ENVI-met air temperature and humidity data were taken from a study by Gouvêa using RAMS (Regional Atmospheric Modelling System) in a citywide study for the same day.

Microclimate Simulation: ENVI-met

To simulate the improvements of thermal comfort due the attenuation of vegetation canopies (at peak thermal stress periods in São Paulo) the microclimate simulation tool ENVI-met (Bruse 1998). These periods occur when the solar angle is almost 90º (vertical). Further the ENVI-met output data was used to derive a logarithmic formula which establishes an approximated relation between mean summer leaf area, transmission of solar radiation and thermal stress below typical street trees in São Paulo (see table 4.2).

The solar radiation was adjusted to 0.7, so that *direct shortwave radiation* meets 700 W/m² which refers (according to Meteonorm 5.1) to the ca. 100 hottest hours of a typical standard year, when radiation is >700 W/m², Solar angle >45º and nebulosity < 2 octas. The canopy transmittance (or the attenuation) of direct radiation is the radiation fraction which has the highest impact on thermal comfort. According to (Moffat and Schiller, 1981) any use of vegetation for improving the microclimate has to exploit judiciously these properties according to site comfort requirements.

Mean radiant temperatures (MRT)

A critical issue in assessing the human comfort outdoors is the need for the mean radiant temperature (MRT) which sums up all short-wave and long-wave radiation fluxes absorbed by a human body (see comfort inices above). MRT is the key variable in evaluating thermal sensation outdoors under sunny conditions regardless of the comfort index used (see Ali Toudert, 2005).

One of the strength of ENVI-met is that it calculates good approximations of MRT. At street level, $E_{t(z)}$ (total long-wave radiation flux absorbed by a human body) on a standing person (cylinder-like shape) is assumed to originate as 50 % from the upper hemisphere (sky, buildings and vegetation) and 50% from the ground.(Ali-Toudert, 2005, p. 71)

A limitation of ENVI-met 3.1 for this study is, that only the direct component of shortwave radiation is attenuated by vegetation, while the diffuse component passes unattenuated, due to the highly unavailability of a model to simulate the complex multiple reflection (defined by leaf albedo, crown density and structure) between leafs inside of the tree canopies.

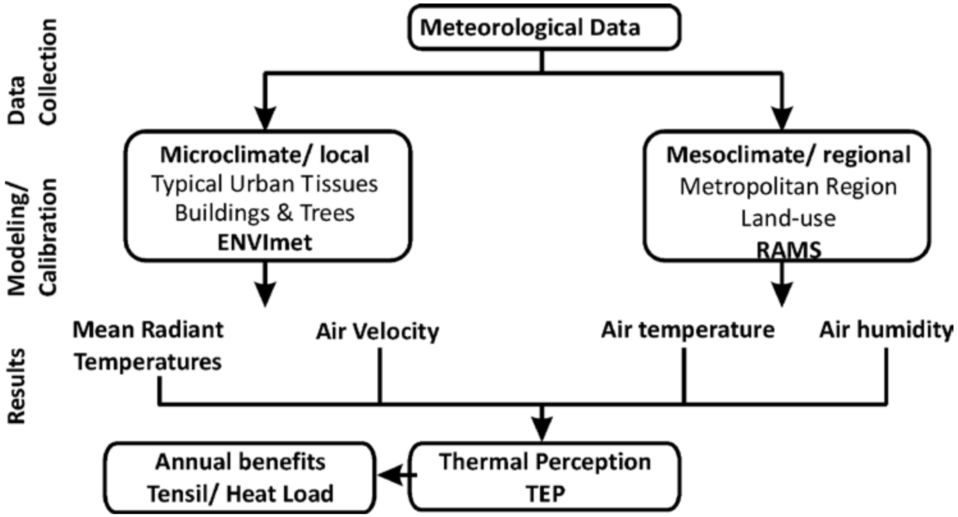


Fig. 6.6: The method developed to estimate thermal comfort based on climate and urban morphology on a day (19th of December) of peak thermal discomfort.

Therefore this study needed to be limited to the indicator of the attenuation of the mean maxima of direct (global) radiation in cloudless hours (during peaks of direct radiation during midday), which were derived hourly data from Meteonorm 5.1.

ENVI-met's standard extinction factor was calculated to 0.5[8], and refers to a high leaf albedo of 0.5. According to the author of ENVI-met different to the direct shortwave radiation, the diffuse component (ca. 14% diffuse sky radiation with input 0 octas) is not attenuated[9] and leads to an underestimations of the summer comfort improvements in the results (7.1.1.)

Air Velocity

Traditionally people in tropical countries used manual fans/ blowers to increase skin evaporation cooling the skin; therefore considering natural ventilation is important and (together with forced ventilation) an interesting low-cost option compared to lowering air temperatures and humidity with air conditioners.

It is further mentioned that only in rather unfrequented situations, when solar radiation is reduced or absent (for

[8] In topical locations leaf albedos are according to Oke (1987) lower, estimated between 0.1 and 0.2 (see chapter 4.1.4)
[9] See A1. [CLOUDS]-Section of ENVI-met 3.1 help

example on cloudy days and at night) and air temperatures are low, air movement can also in the tropics lead to and increase cold stress, like common in temperate and cold climates.

Wind is due to highly varying changes in speed and direction difficult to simulate but an important parameter in hot climates, because it air movement leads to increased evaporation and convection rates and thus energy savings and increased thermal comfort through the evaporation of skin humidity and convection on building envelopes. As discussed in 5.2.2 a drawback with urban trees is that they block the wind, decreasing the dispersion of pollutants and thermal comfort. Ali-Toudert and Mayer (2007) estimated that a deciduous tree may reduce wind speeds by 30-40%.

Unfortunately the potential wind-energy is low within the *urban boundary layer* if megacities due to their general roughness (cubic morphology with sharp-edged buildings, closely spaced) which generates turbulence[10] and a rapid loss of kinetic energy[11]. As mentioned before the impact of tree shade is more effective on thermal comfort than the drawback of decreased wind speed.

Macroclimate Simulation RAMS

There are certain limitations of calibrating the microclimate model ENVI-met to tropical climatic conditions (see Spangenberg (2004, Johannson 2006, Spangenberg *et. al.* 2007) without *forcing*[12] the model with external data. Since is was not possible to simulate the daily courses of air temperature and humidity, parameters necessary to estimate the thermal comfort indicator of Perceived Effective Temperature (Monteiro 2008) with ENVI-met temperature, humidity data were derived from a study by Gouveâ for the same day.

The atmospheric model RAMS (Regional Atmospheric Modelling System, Pielke *et al.,* 1992, Cotton *et al.,* 2003) it is a numerical model of multiple purpose, designated to simulate atmospheric circulations at different scales (Freitas, 2003). The initial concept of the model was created by the University of the State of Colorado (CSU - Colorado State University), USA, in the 1980s and is being perfected along the years (Tremback and Walko, 1997). It is being used broadly nowadays, as well for operational purpose as for research (Gouvêa, 2007).

Gouvêa (2007), also simulating the benefits of vegetation on air temperatures showed in various experiments that the urban surface turbulent fluxes (see especially the Bowen ratio latent/ sensible heat flux) are considerably changed and that air temperatures are gradually reduced by up to 1.5 ºC when 50% of the

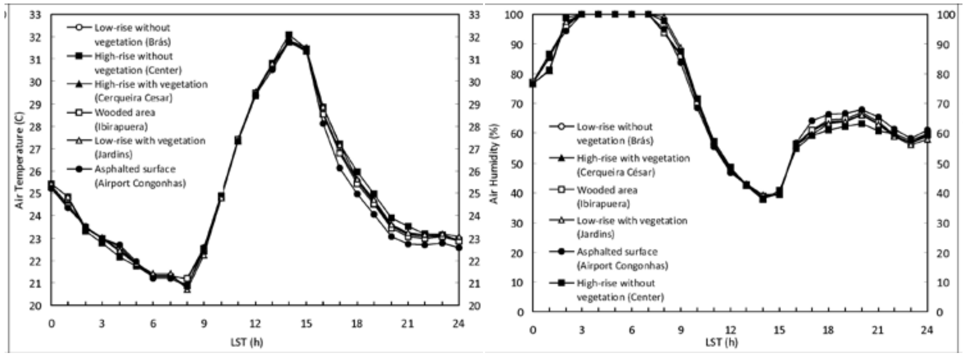


Fig. 6.7.: Output RAMS 4.3, Macroclimate (simulations by Mariana Lino Gouvêa) of shows that the differences of air temperature (left) and humidity (right) between the six analyzed tissues vary especially during the cooling period at night

urban surface are replaced by vegetation, reaching a maximum of 2.2 ºC when 100% of the urban surface was replaced by vegetation cover. Compared to other studies, (e.g. Alexandri *et al.* 2006, see fig. 6.11), which simulated a decrease in urban temperatures at city-wide scale by 10ºC for São Paulo latitude if all buildings were greened, these values appear low.

6.2.2 Energy Conservation of Buildings

Natural indoor thermal comfort is principally generated by tree shade and secondarily due to local evaporation cooling from vegetation. This combination leads to decreased cooling loads and thus decreased (or no) energy consumption for cooling. Unfortunately the benefit is limited to low-rise (usually residential) buildings since greened buildings are yet exceptions in São Paulo.

Shashua-Bar and Hoffman (2000) estimated in Tel Aviv (N 32º), that shading was responsible to be at 80% of the cooling effect of vegetation and evapotranspiration cooling to only 20%. The same tendencies were shown in the micro- and macroclimate studies (see preceding chapter) and the measurements at different scales presented in table 3.1. for São Paulo.

They show, that neighbourhood evapotranspiration cooling decreases

[10] The intensive mixture of air within the boundary layer, characterized by roughness and consequently turbulence dissipates energy, emitted from surfaces and which also dilutes air temperature measurements. Air movement carries masses of air, either heated up, or cooled down (advection) on highly complex paths (mainly horizontally). At a regional scale masses of air cooled by evaporative processes by vegetation or water can enter the city through so called “cold-air generation corridors”.
[11] Recently several sustainable architecture proposals use its potential at high altitudes on high-rise buildings to generate energy (wind harvesting) (see e.g. Ken Yeang).
[12] Applying the “forcing“ concept to ENVI-met remains future work. According to the author as a microscale model, ENVI-met does not have enough reliable information at its boundaries about mesoscale meteorological effects or general weather dynamics outside its limited spatial region. To simulate specific meteorological conditions, it is possible to force the model with external data (e.g. atmospheric profiles).

air temperatures up to reported limited maxima of only 5°C, in neighbourhoods with a maximum greening degrees (like the *Garden Neighbourhoods*) and on lee sides of larger urban on hot days, which results generally results in energy efficiency but the exact savings are difficult to obtain.

However, due to the aforementioned contradiction between desired decrease of cooling loads on one hand, but also an undesired decrease of lighting levels in the lower storeys on the other (see Velasco, 2007 and Pietrobon, 1999) the attenuation of radiation by vegetation (and thus leaf density) should be limited. Schoepfer and Lang (2005) point out the importance of "finding the right tree shadows" to establish an optimized balance between shade and illumination - is one of the most important aims to achieve energy efficiency of buildings, especially in the tropics.

Especially the impacts of heat load and efficient use of natural light are due to be central key indicators for Brazil's first (and voluntary) energy saving legislation, which takes also the *National Bioclimatic Zoning* of the countries different climates and radiation income into account (Silva *et. al* 1995).

According to ASHRAE (2004) set-points of cooling facilities inside of buildings can be determined by urban local ambient temperatures and humidity (without considering shading coefficients). Thus each ºC of elevated air temperature of due to *urban heat islands* have an important negative impact on energy consumption, while *summer oasis islands* decrease cooling loads through evapotranspiration cooling (see 4.1.4). Since the electricity demand is highly sensitive to temperature (Rosenzweig *et. al.* 2001) the urban climate has an important negative impact on the energy consumption of buildings in warm and hot locations (see Joyce *et. al.* 2001).

Ali-Toudert (2005) resumes that while in cold climates using the vegetation as screen against high winds is more appropriate while in hot climates, the best use of the vegetation should profit from its shading property to mitigate the intense solar radiation in the summer as the overheating is mainly due to the storage of heat by the sunlit surfaces (McPherson *et. al.* 1994b).

6.2.2.1 Energy Matrix of Brazil and CO_2 Emissions

It is important to analyze briefly energy production in Brazil because buildings are responsible for 45% of all consumed energy mainly for artificial light and cooling (Lamberts *et. al.* 1997). Urban trees improving energy efficiency of buildings thus have thus a secondary indirect benefit: the avoidance of CO_2 emissions for energy production (see Jo *et. al.* 2001), which points out again the reciprocal connection between energy development and environment (see Goldemberg 1995).

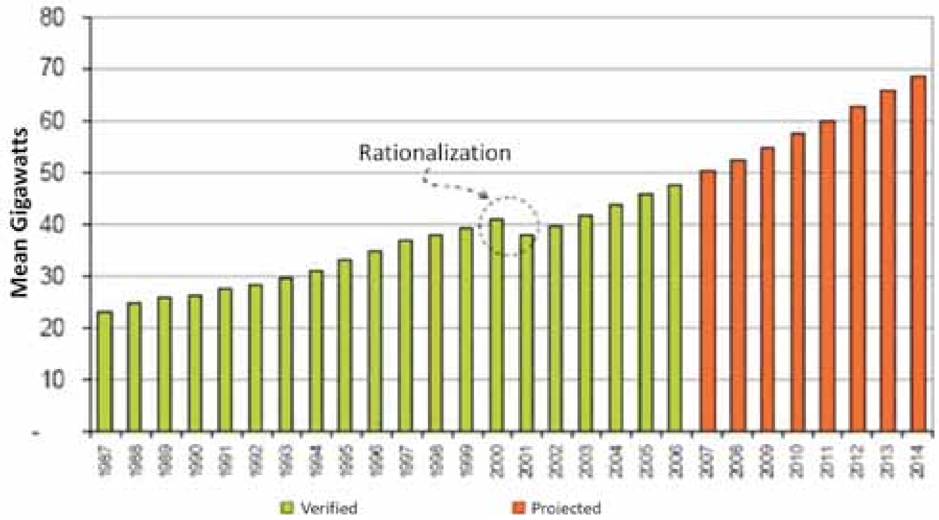


Fig. 6.8: Demand of electric energy in Brazil Projection from 2007 MPX Business Plan Brazil`s ONS. Energy consumption will have been tripled in between 1997 and 2014.

Energy, material resources and climate were since the beginning the industrialization the base of Brazil's development. Today the national energy matrix presents an exemplary energy-mix due to the efficient use of the hydrological potential. In 2008 still more that 90% of the national energy potential still was produced by hydropower plants.

But unfortunately the energy matrix is changing towards a less sustainable one which will burn more coal, mainly due to limitation of access of the hydrological potential and delays of environmental legislation and permission processes for barrages and storage lakes. It is also discussed that the large artificial water reservoirs of hydropower plants have strong impacts on climate due to land-use change and because they emit large quantities of greenhouse gases because of internal vegetal decomposition.

As a tendency the national energy matrix shifts towards non-renewable, CO_2 emitting facilities, but other renewable energies like biomass and wind also play important roles in future scenarios and generally an increased energy efficiency could be achieved in combination with the aforementioned renewable energy generation (principally decentralize solar, wind and biomass facilities) which could be a sustainable and feasible strategy for Brazil.

In the past the most densely populated regions of São Paulo and Rio de Janeiro have suffered from water and energy dropouts and restrictions, due to the failure of the energy network. Ironically the urban water networks also fail when torrential summer rainfalls cause urban inundations due to soil sealing. However the dropouts led to a certain sensitization of the population in terms of the limits of energy (and water) resources in 1994 and 2001.

As Brito (2008) reported the countries energy matrix potential is delayed by one Itaipú hydropower station (60MW) due to increasing the increasing consumption, especially in urban areas (and especially due to more air conditioners. Since supply energy is crucial for development the underestimated proliferation of energy efficiency is an important (but underrated) support to avoid future energy crises.

6.2.2.2 Impact of Urban Trees on Energy Efficiency

As mentioned, trees contribute to energy efficiency mainly in low-rise residential areas, which cover ca. 9% of São Paulo's municipal area, but the potential of a functional use of vegetation to cool greater regions if used in new but (retro-)innovative forms must not be underestimated and will be discussed later (see 7.4).

In various studies in the United States the impact of vegetation on energy efficiency (for decreased cooling and for heating loads has been analysed. According to Akbari *et al.* (2001) peak energy demand in the United States rises 2–4% for every 1°C increase in maximum air temperature above a threshold of 15 to 20°C. The additional air conditioning use is responsible for 5-10% of urban peak electric demand at a direct cost of several billion dollars in the U.S. annually.

Another recent study found that planting shade trees could reduce the need for power plants. Data from California shows that 50 million shade trees planted in strategic, energy-saving locations could eliminate the need for seven 100-megawatt power plants (McPherson and Simpson, 2001). A study of Chicago's urban forest found that increasing tree cover by 10 per cent (an additional three trees per building) would reduce total heating and cooling energy use by 5 to 10 per cent.

Shade and evapotranspiration cooling from trees have been found to reduce cooling costs by 20-50 percent (Dwyer, 1993; Laverne and Lewis, 1995). At a national level, researchers estimate that planting three additional trees for each building in the United States could save more than US$2 billion in energy costs annually.

In densely built environments, trees can be located in places, parking areas, street intersections or in rows along the streets. The usefulness of the latter solution should not be underestimated as reported by McPherson (1994) and McPherson *et al.* (1999). They found for Chicago large economies gained from green cover, from which one-third consisting in alignment of trees in urban streets. The vegetation leads to the most energy savings if planned in residential areas where the energy needs are high, i.e. yards or streets, from 50% to 65% of energy savings.

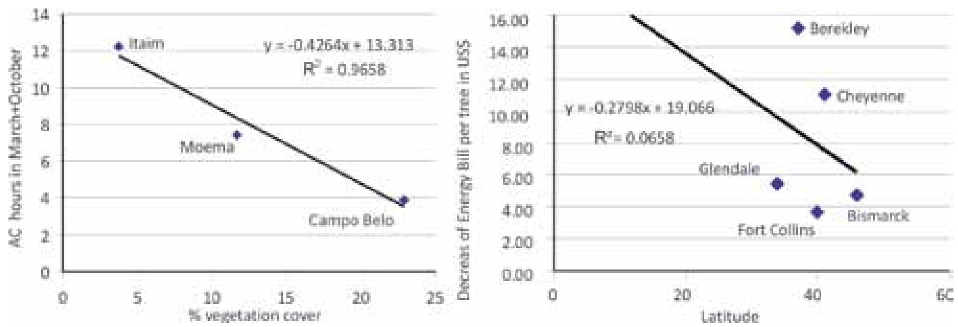


Fig. 6.9: Air conditioning hours in the months of October and March in relation to percentage of vegetation cover in three districts in São Paulo, derived from Velasco, 2007, (left) and Decrease of energy bill per tree in US$ in 5 U.S. Cities according to latitude derived from McPherson et. al. 2005 (right)

McPherson and Simpson (1995) assessed various trees' properties on energy savings finding that tree efficiency depends highly on orientation, which means that strategically trees planted to shade homes can significantly reduce their air conditioning bills.

In Brazil the studies which analyze the impact of trees on energy consumption are few. The aforementioned study by Pietrobon (1999) carried out measurements of transmission of solar radiation through tree canopies of four species located close to buildings during one year in Maringá (Parana State, S 23°). Pietrobon also applied thermo-luminous *VisualDoe* simulations and indicated a possible energy efficiency of 14% to 57% for school buildings, if the trees are strategically positioned.

Velasco (2007) analyzed the potential of street trees to reduce energy use in tree low-rise districts in São Paulo (S 23º), applying questionnaires on energy consumption of households. The low-rise residential neighbourhoods in Itaim (vegetation cover 3.71%), Moema (vegetation cover 11.71%) and Campo Belo (vegetation cover 22.92%) showed maximum differences of air temperatures of 2.41°C and mean differences of only 0.09ºC, but also an increase of the application of air conditioning equipment which varied between 3.91 and 10 hours in March and 0 and 2.25 hours in October. Thus a correlation between vegetation cover and open skies above the three different urban tissues was found.

Energy Consumption of different Typologies

The energy consumption of buildings in the tropics depends mainly on their lighting and cooling. Finding a balance between daylight access and the set-point for cooling equipment (to remove the thermal load from the building) is one of the most important aims to achieve energy efficiency of buildings.

While tree shading in open public spaces leads beyond doubts to thermal and visual comfort of occupants (see chapter 2.4) in public spaces, during daylight hours, but dense vegetation covers can also lead to very low daylight levels an thus energetic inefficiency (especially in the lowest two levels of a building) due to increased artificial lighting.

In other words: It is surely one of the most important - and at the same time complex tasks - of climate responsive architectural planning in the tropics to find the ideal relation between daylight access (depending on urban geometry, sky view factor SVF, vegetation (see fig. 6.5), wall-window-ratio WWR and albedo) and passive cooling/ shading (depending urban geometry, shading elements, vegetation).

Admittedly the annual direct and indirect radiation (and illumination) changes and shade patterns within local urban situations are by far too complex to be generalized, but for planners considerations of solar path inclinations are highly useful as planning tool in regions where a minimum heating of the urban structure is desired.

In summary the energy consumption of buildings in the tropics depends to a larger degree on the external urban - built and planted – and thus morphological configurations than in the temperate climate zones. The aim in tropical regions should be to optimize the *Zero energy hours* of buildings.
Crucial however is the climatisation concept and the decision whether the building is

- **naturally ventilated** (also called *bioclimatic*),
- **sealed and air conditioned**
- **mixed-mode**

This decision certainly changes the relation between the public and private space, the separation into indoor and outdoor space (and thus climate and energy use for climatisation) (see 3.2) The Dutch urban planner Kees Christianse focuses on these questions in his *Open City* projects (see Christanse, 2008[13]).

In Brazilian cities air conditioning is mainly applied to sealed office buildings, which tend to have curtain walls (more or less from the period of the construction of Brasília), and often shading elements (like *brise soleil,* introduced in Brazil by Le Corbusier in the late 1920s) were dispensed because at the time of their construction energy was cheap and abundant. This

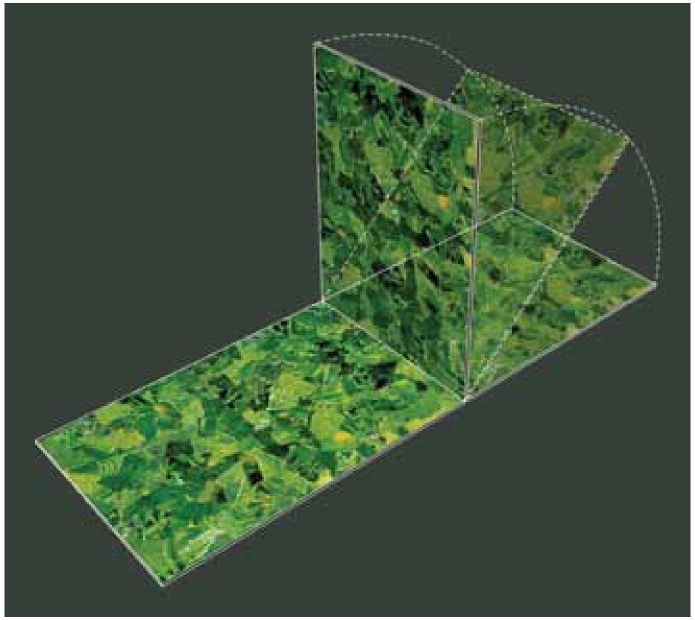


Fig. 6.10: Tree-shaded low-rise residences in São Paulo's Garden Neighbourhood Jardins (above) and principle of folding horizontal vegetation cover (or "landscape") into a vertical direction

[13] http://www.urban-age.net/0_downloads/pdf_presentations/SaoPaulo/_conf/035_KeesChristiaanse.pdf
[14] The abbreviation PLEA stands for Passive and Low Energy Architecture http://www.plea-arch.net/PLEA/Home.aspx <access on 29th of June 2009>

building typologies consume enormous and increasing amounts of energy.

The energetically negative, proverbial "Ice-T"-effect, refers to the paradox principle to first consume energy to heat up a fluid and then use more energy to cool it down (see Spangenberg 2008). As mentioned, in hermetic not-naturally ventilated buildings air temperature and humidity are the crucial parameters to dimension the potential and set point of the HVAC, while in open, naturally ventilated (bioclimatic) buildings mainly local radiation and wind conditions are taken into account. Hien and Jusuf (2007) recommend for example micro-climatic external studies with ENVI-met to generate input for internal TAS simulations at building scale.

According to São Paulo's climatic conditions it is assumed that it was possible to construct buildings applying only passive climate control strategies dispensing air conditioning (see *National Bioclimatic Zoning* by Silva *et. al* 1995 and various articles presented in PLEA-conferences[14]), but often the urban situations tend to represent elevated noise and air pollution levels (mainly caused by traffic) and elevated external temperatures, which are the most often stated reasons for the decision of hermetic, sealed façades.

The Latitude Theory

Various recent works found that that high-rise buildings (above two storeys) in the Tropics can also directly benefit from vegetation shade if the greening concept is extended vertically (see fig. 6.10) through green roofs green fascades because (overlayed) vegetated surfaces are one of the few available strategies to keep constructed surfaces and ambience cool, increasing urban energy efficiency.

According to *The Latitude Theory* (based on Taha, 1997 and Alexandri and Jones, 2006) the thermal (and energetic) benefits of urban vegetation increase with decreasing latitude. Alexandri and Jones (2006), found modelling urban vegetation (green roofs and facades) in six cities worldwide (all located in the northern hemisphere, except from Brasília) that the lower the latitude of the city (the more tropical) the higher the effect of vegetation on urban air temperatures and the more effective on the energy consumption of air conditioning equipment.

Applying an empirical formula derived from the results in São Paulo (S 23º) this would result in a drop of urban air temperatures of 9.76 ºC and a drop of daily air conditioning hours to ca. five hours if all buildings were greened due to shading and evaporation cooling.

In tropical latitudes the roof, or the fifth façade, as Le Corbusier named it, receives the highest radiation income of all building surfaces during the summer, therefore green roofs have the highest impact on climate and energy consumption keeping the roofs cool and mitigating the urban (surface) heat island.

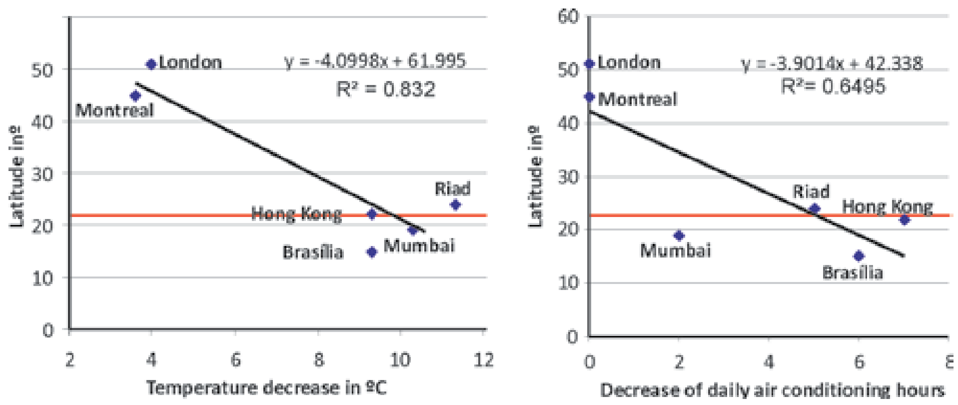


Fig. 6.11: The Latitude Theory based on simulations by Alexandri and Jones (2006), shows benefits of urban vegetation increasing with decreasing latitude, the red line marks São Paulo's latitude (regressions derived by the author)

Especially for isolated high-rise buildings exposed to direct radiation, green facades as alternative shading elements (instead of, or additionally to *artificial shading elements* like *brise solei*) also result in increased direct benefits of urban vegetation by decreasing the thermal load and thus decreased set points of the increasing number of air conditioners which widely cool indoor environments in tropical cities.

6.2.2.3 Modelling method

CITYgreen 5.4 (American Forests, 2002) for ArcView GIS (ESRI[15]) includes a module to estimates on-site energy savings from direct shading of one- and two-story residential buildings in small area analysis, considering local climate (which also influences related tree growth rate information), roof albedo (which also contributes to energy conservation, see 4.1.3[16]), localization of air conditioning equipment and local cooling costs etc. to estimate the dollar value of the *direct shading benefits* that trees provide to buildings assigning an energy rating.

The following seven tree parameters are taken into consideration to estimate the residential cooling effects of the trees:

- **Leaf Density**
  (Light, medium, dense)
- **Leaf Albedo**
  (High, middle, low)
- **Height Growth Rate**
  (Fast, medium, slow)

[15] http://www.esri.com/ <access on 29th of June 2009>
[16] http://eetd.lbl.gov/HeatIsland/ <access on 29th of June 2009>

- **Height Class**
  Short < 7.60m (25 feet), Medium 7.60 – 13.70m (25-35 feet) and Tall > 13.70m (45 feet)

- **Diameter Growth Rate**
  (Fast, medium, slow)

- **Crown Form**
  (Scrub, Dense Small crown, Columnar, Pyramidal, Oval, Vase-shaped, Round, Spreading)

- **Leaf Persistence**
  (Broad Leaf Deciduous, Needle Leaf Deciduous, Broad Leaf Evergreen, Needle Lead Evergreen, Semi-Evergreen)

Additionally the following local six parameters are coupled and are taken into account:

- **Local Climate**
  (In CITYgreen included is climate data for 17 U.S. cities)

- **Cooling Cost**
  (Associated with running an air conditioner during the summer)

- **Roof Albedo**
  (Black, Dark Gray, Light Gray, White)

- **Roof Insulation**
  (R-Value, a rating from 1-60)

- **The Distance of the Tree from the Building**
  (Only trees at distance of up to 10.50m or 35 feet are considered)
  Position/ Orientation relative to Buildings
  (North, East, West, South)

- **Ability to shade a Window and/or air Conditioner**
  (Position relative to building North, East, West, South)

Pietrobon (1999) concerned about energy consumption for illumination gives even three more important parameters to optimize energy consumption benefits of vegetation which are not considered in CITYgreen: The optimization of the system of artificial lighting, inertia and isolation of the walls and wall-window ration (WWR).

Since the benefit of energy conservation is (aside of thermal comfort in open spaces) of the most important direct environmental benefits it should interest occupants and planners interested in functional, energy-saving design of the buildings surrounding is important.

However, it is difficult to make citywide estimations of this benefit because it is locally restricted and depends on too many parameters involving urban geometries, variations of diameters, shape and volume of trees. Only a larger number of small area local inventories and case studies based on randomly chosen representative strata investigations could bring meaningful results. In a megacity like São Paulo least forty small area analyses would be recommended to derive representative mean values for annual energy savings per tree.

Administrative Regions		Area [km²]	% urbanized	Districts	Inhabitants
City Center	C	16	100	8 Districts	326,349
Expanded Center of São Paulo	CE	140	100	24 Districts	1,371,222
Municipality of São Paulo	MSP	1509	57	95 Districts	10,230,613
Metropolitan Region of São Paulo	GSP	8051	82	39 Municipalities	18-21 Mio.

Table 6.3: Overview of boundary options considered

Due to these difficulties an empirical value derived by McPherson *et. al.* (2005) for the city of Berkeley (California) will be used to monetize both, thermal comfort in public (open) spaces and energy conservation for cooling of (indoor) spaces of buildings applied, probably underestimating the value of vegetation benefits on the urban climate. The results are presented in chapter 7.

6.3 Indirect, citywide Benefits

To estimate the important (but less appreciated) indirect, citywide and regional benefits São Paulo's urban forest, *CITYgreen* (American Forests, 2004) for ARCGIS 9.2 (ESRI, 2006) was applied. The model allows citywide analysis based on classified vegetation remote sensing data, combined with local models derived by urban foresters in North America (see McPherson, Nowak and others). The model created in the United States has therefore certain limitations when applied to Brazilian urban-regional conditions.

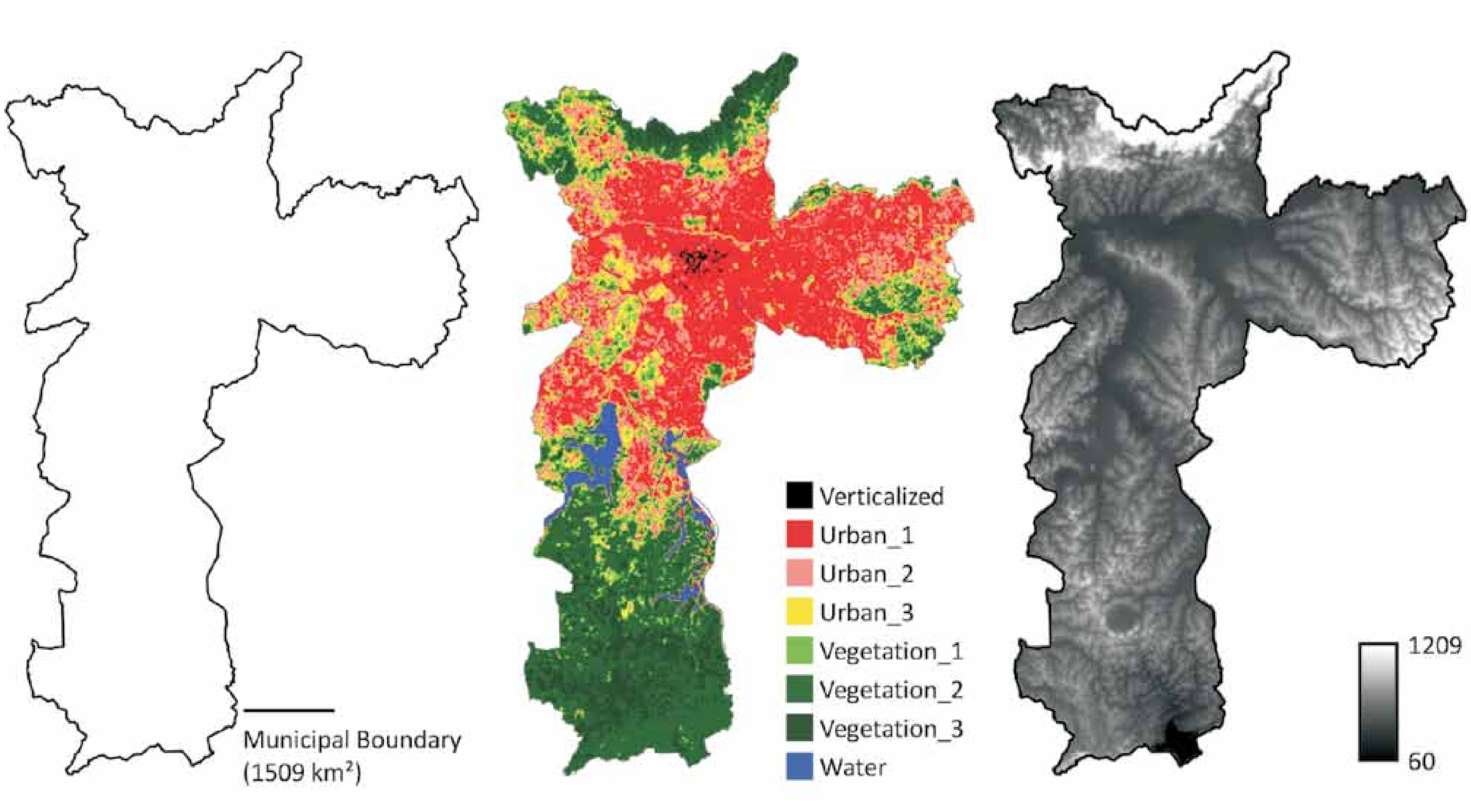
Aiming for the international application of the software the authors of *CITYgreen* call American reference cities *surrogate cities* because they roughly reflect the local climatic conditions and benefits of urban forests in Brazil (e.g. air pollution data from Los Angeles combined with subtropical climate data from Miami/ Florida).

As mentioned before tropical urban ecosystems may be more efficient in terms of environmental services due to partly evergreen vegetation and an all year growth period, which especially applies to CO_2 sequestering and growth but they also tend to be more vulnerable. Generally the climatic influences (radiation and rainfall) are more abundant in São Paulo than in most U.S. locations and efforts were made to adjust the tool to Brazilian conditions but further calibrations of the simulation tool for national Brazilian urban conditions remains future work.

Definition of Area of Interest (AOI)

As mentioned before one of the most important steps of environmental

Fig. 6.12: City-wide regional ecosystem analysis Area of Interest (Municipality of São Paulo), Distribution of Vegetation Cover and Topography (Projected coordinate system in South American_1969_UTM_Zone_23S, without scale)



modelling is the definition the spatial boundaries, in the so-called *area of interest* (AOI), the temporal boundaries of *CITYgreen* are defined by an annual basis. Since this part of the study is - in contrast to the local case studies on thermal comfort – a regional city-wide study, the possible boundaries were studied carefully.

Generally investigation boundaries bear the danger of distortions and inaccuracies, but are necessary to limit calculations. The following boundaries were considered and analyzed to estimate benefits and the value of urban vegetation within the city:

- **City Center**
  Since the degraded central region of the city, the original CBD (consisting of eight districts, or sub-municipalities around the *Patio de Colégio*, see fig. 3.3) represents the lowest fractions of urban vegetation, it was first considered to estimate indirect benefits of urban vegetation, until it became clear that the benefits are of the sparse vegetation are very limited and would not represent the role of urban vegetation within the whole city. However, vegetation plays an important role in the revitalisation process of the center of São Paulo.

- **Expanded Center**
  The so-called *Expanded Center* (also called Mesopotamia because it is limited by the rivers Pinheiros in the West and Tiête in the North and the area of the *alternate day traffic* system *(Rodizio)* since 1997 was focused next, until it became clear that analyzing only this area would socio-economically and geographically not correspond to the ideal principal of an equally developed concentric city because the so-called *Expanded Center* stretches much further into the western region than into the eastern.

- **Ten Kilometre radius around the City Cente**r
  The following approach analyzed the central region within a radius of 10 kilometres around the City Center (Sé/República), an area of 314.16 km², including the area of the *alternate day traffic* system of 23 districts plus 22 districts (altogether 45 districts).

  Generally this boundary (which exceeds the municipal boundaries at two points in the South-East and in the North East) represents best the highly sealed land-use of metropolitan area with a diameter of 20km because it excludes the forests in the peripheries. This core region is also the area where:

  • the surface urban heat island (identified by remote sensing) is most distinctive
  • the socio-economical (and environmental) and UQL indicators are most rich in contrast
  • the most intense fluxes of vehicles occurs
  • the highest outmigration rates occurs
  • the lowest vegetation indices are found

The original idea was to estimate only the benefits from urban vegetation (street trees, parks etc.) excluding e.g. the forests in the peripheries but the discussion on the boundaries shows the difficulties to define which vegetation is urban. American Forests (2004) have pointed out, that “some of the worst environmental degradations we face today occur at scales that transcend political boundaries”, which is especially true on the boundaries of the municipalities of the metropolitan region of São Paulo, where urbananization spills over political boundaries.

It was concluded that choosing the whole municipal area (like in all the aforementioned U.S. studies) would be the best choice, also due to data availability, accepting that regional benefits (which derive mainly from the peripherical forests) are included. The advantage of this choice is that it alerts about the importance of the whole urban forest and allows indications for the city government.

- **Municipal Area**
  The municipal area of São Paulo has a size of 1509 km² but, according to the Environmental Atlas (2000), only 870km² of this area is urbanized. The municipal boundaries stretch in their northern districts into the forested *Cantareira Mountain Range* and the southern districts into the forested *Costal Mountain Range*) into rural (non-urban) districts with large fractions of primeval forest, which leads to the aforementioned distortions. On its western and eastern boundaries municipal area of São Paulo is directly connected to other municipalities and densely urbanized areas.

The following data was used to estimate city-wide benefits of São Paulo’s urban forest on stormwater retention, air pollution removal, soil quality and CO_2 sequestration:

1. **The *Limits of the Municipal Area*** (shapefile), boundary of the AOI, was taken from Fundação Sistema Estadual de Análise de Dados (SEADE) online[17] (also available on the annual Sensus Data CDs). The analyzed area has a size of 1509 km² and houses ca. 11 million inhabitants.

2. **The *Distribution of Vegetation Cover*** (geoTIFF) was kindly supplied by Flavio Laurenza Fatigati specialist with the SVMA. The classification was derived from remote sensing data of Landsat 7 ETM+ 03.09.1999 separating spectral properties of vegetation cover and other land use into eight classes and originally generated for the *Atlas Ambiental* (SVMA, 2000). The data has a spatial resolution of 30 x 30 meters.

[17] Fundação Sistema Estadual de Análise de Dados - SEADE
http://www.seade.gov.br/projetos/eatlas/downloads.php?PHPSESSID=e15528b27a409bb6369c82f31388ad02

Limitations

Acquiring classified data of São Paulo's urban vegetation cover suitable for this analysis was difficult. Classifying land-use on the base of satellite images is a highly sophisticated process because thresholds of pixel-values have to be defined according to wavelength and reflection values which include *fuzziness* and need professional adjustment. For this classification (according to the authors) all areas were considered vegetated which showed spectral responses of vegetation including not only trees but also scrub and grasses.

Higher resolutions and more recent data would be desirable, since the vegetation cover of the municipal area of São Paulo decreased significantly (by ca. 10%) during the last decade. The more recent land-use classification by EMPLASA (2006) was analyzed but could not be used because the data was *ground-truthed* excluding vegetation cover.

The spatial resolution of the Landsat image captures only vegetation fragments larger than 900m² (30m x 30m). The indicator therefore cannot be read as an equivalent of the existence of whatever green area in the city because it does not detect small areas or isolated street trees.

Although valid, generally higher resolutions and more vegetation classes are recommended by American Forests to increase the exactness of the *Rapid Ecosystem Analysis* with *CITYgreen* allowing a more exact determination of the vegetation cover of even isolated trees. The existing file allows distinguishing urban greening degrees of e.g. *Garden Neighbourhoods* but not single tree crowns.

The following section describes how the original land-use classification of the SVMA (2000) was re-classified in CITYgreen to carry out the calculations. Note that the classes 1-3 describe urban tissues with a minimum greening degree, while 4-7 have vegetation cover but different understory properties.

1_Shadow (Black)
Description: Most verticalized regions with great concentration of buildings
Examples: Old Center, principally the districts República, Sé, Brás e Santa Cecília, also along Paulista Avenue and State avenue (Avenida do Estado) (SVMA, 2000)
CITYgreen classification: Urban: Commercial/ Business

2_Urban_1 (Red)
Description: Densely urbanized area with sparse vegetation. Great quantity of buildings, roads with few street trees and few squares and private gardens
Examples: Concentrated in the expanded center, stretches into the east zone (SVMA, 2000)
CITYgreen classification: Impervious Surfaces: Buildings/ structures: All other buildings

3_Urban_2 (Pink)
Description: Regions with dense urbanisation and sparse of vegetation. Differs from Urban_1 through the predominance of condensed horizontal residential neighbourhoods. Roads with few street trees and also few squares and residential gardens.
Examples: Standard met principally in the consolidated urbanisation on the peripheries of the municipality (SVMA, 2000).
CITYgreen classification: Urban: Residential: 0.125ac Lots

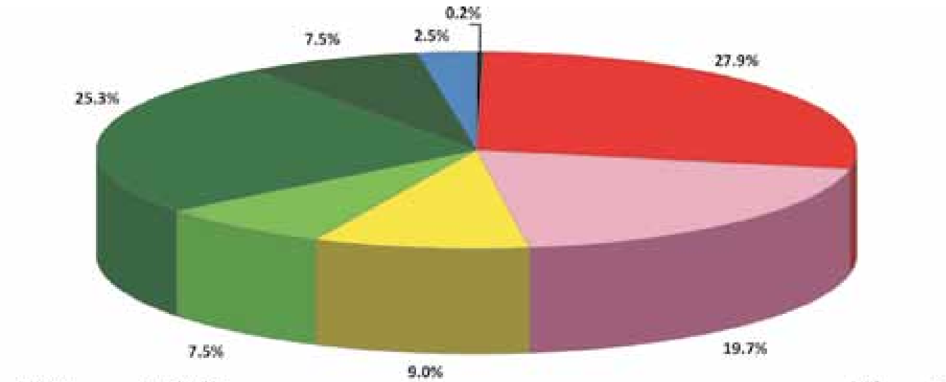
4_Urban_3 (Yellow)
Description: Intensively greened regions (Garden Neighbourhoods) and areas of urban expansion (SVMA, 2000).
Note: Especially for this layer a higher resolution would be desirable, since it captures only vegetated areas larger than 900m² (groups of 9-12 large trees). In order to substitute all the inner-city vegetation (1.5 million street trees) it was considered as 100% covered.
Examples: Garden Neighbourhoods: Jardins, Alto de Pinheiros e Alto da Lapa, Granja Julieta, Interlagos etc. Áreas of urban expansion: Distrits Pirituba, Jaraguá e Perus ao Norte; Guaianazes, Cidade Tiradentes, São Rafael e Iguatemi a Leste; Parelheiros and Grajaú ao Sul (SVMA, 2000).
CITYgreen classification: Trees: Impervious understory

5_Vegetation 1 (Light Green)
Description: Urban Parks and Bosks
Examples: Parks (Parque Do Estado, Ibirapuera, Carmo etc.) (SVMA, 2000).
CITYgreen classification: Open Space - Grass/ Scattered Trees: Grass cover < 50%

6_Vegetation 2 (Dark Green)
Description: Rural Zone including, jungle, reafforestation and agriculture (*Floresta ombrófila mista Secundária Inicial (capoeira)*
Examples: Cantareira, Environmental Protection Area (APA) of Capivari-Monos etc. (SVMA, 2000).
CITYgreen classification: Trees: Grass/ turf understory: Ground cover 50% - 75%

7_Vegetation 3 (Very dark green)
Description: Conifers and Broadleaf *Floresta ombrófila mista Secundária Tardia (capoeirão) Floresta ombrófila mista densa Montana Atlântica (capoeirão) Floresta ombrófila mista densa Alto Montana (Nebular) (capoeirão)*
CITYgreen classification: Trees: Forest litter understory: No grazing, forest litter and brush adequately cover soil

8_Water (Blue)
Description: Water reservoirs, lakes, rivers
Examples: Water reservoirs Billings, Guarapiranga, Rivers Tietê, Pinheiros, Lakes in parks, etc.
CITYgreen classification: Water area



SVMA	CITYgreen	km²	%
VERTICAL	Urban: Commercial/Business	3.54	0.2
URBAN 1	Impervious Surfaces: Buildings/ structures: All other buildings	422.30	27.9
URBAN 2	Urban: Residential: 0.125ac Lots	298.19	19.7
URBAN 3	Trees: Impervious understory	136.97	9.0
VEGETATION 1	Open Space - Grass/Scattered Trees: Grass cover < 50%	113.76	7.5
VEGETATION 2	Trees: Grass/turf understory: Ground cover 50% - 75%	387.88	25.6
VEGETATION 3	Trees: Forest litter understory: No grazing, forest litter and brush adequately cover soil	113.77	7.5
WATER	Water Area	37.87	2.5

Fig. 6.13: Quantification of the eight vegetation density classes of the City of São Paulo (SVMA, 2000) and re-classification in CITYgreen

3. ***The Topography Model*** (level curves each 5 meters) was derived from data kindly made available by the *Laboratório de Sensoramento Remoto* of the Department of Geography (FFLCH) of the University of São Paulo. Level curves above 1000 and below 500 and the geographic coordinate systems were adjusted. The raster topography DEM-Model was generated with the same grid size as the GeoTIFF of the vegetation cover with 30x30 meters. Levels above sea level within the municipal area are ranging from 59 m in the district Marsilac (in the extreme south) up to 1209m (Pico de Jaragúa).

   Subsequently the three datasets were coupled in CITYgreen and ARCGIS 9.2 with further input data to estimate (quantify) decreased costs for stormwater management, air pollution removal and carbon sequestration of the urban forest within São Paulo's municipal area.

6.3.1 Stormwater Retention

The water cycle is intimately linked with the energy cycle, triggers and enables bio-physiological processes like photosynthesis, evapotranspiration etc. resulting in plant growth. Water availability is like solar radiation crucial for the survival of all life forms: plants, animals and humans (see Kravcík, *et. al.,* 2007). Plants retain water on

Fig. 6.14: Stormwater events in São Paulo sometimes causing death victims (Cenofanti and Brancatelli, 2006)

leafs, absorb rainwater from the soil through their roots retain the water their in structures and subsequently evapotranspirate it through leaf stomata.

The evapotranspiration of water from plant surfaces and soils is interlinked with the formation of clouds the most important regional (and global) cooling mechanism, (see 4.1.4.) and subsequent rainfall itself has as well important cooling (and air cleaning, see following chapter) functions. But in impervious cities the evaporation cooling potential is not well utilized due to rapid runoff of the rainwater on impervious surfaces and reduced retention in (unsealed) soils and on leaf surfaces.

An improved stormwater management is especially important in megacities in tropical latitudes like São Paulo, were inundations are common during and after torrential stormwater events in the summer, due to impervious surfaces, quick runoff and topography/ hilliness. Retention and drainage of the stormwater on vegetation covers and associated open soils are a comprehensive alternative to retention facilities like stormwater retention basins/ fr*ench drains* (*picinões*). São Paulo's legislation forces owners to retain rainwater on the property.

Analyzing climate data from São Paulo showed that maximum rain gauges are about three times higher than in the temperate climates. Apart from being frequent the number of exceptional thunderstorm events increase in the metropolis due to the urban heat island. Stormwater management is therefore a priority issue and fabricated solutions like grass and/or porous pavers or permeable asphalt are recommended in São Paulo.

An improved stormwater management (in combination with sanitation) has also positive effects on erosion and drinking water quality and is one of the most important issues and which causes high direct and indirect costs in São Paulo.

According to Robba and Macedo (2003) at present due to massive processes that render the soil impermeable, cities face problems that may be minimized with proper policies of implementation and distribution of permeable areas. The authors point out that landslides and washouts may be prevented by not leaving the soil exposed to the effects of rain and that planted surfaces help to avoid erosion and mountain-slides through roots and structure.

When rain cannot infiltrate the ground where it falls, it turns into runoff. Speed and volume give water its erosive force, as well as the ability to carry sediments over long distances. As recommended by Thompson and Soving (2000) in their excellent guide book *Sustainable Landscape Construction – A Guide to Green Building Outdoors*, as a result, controlling water quality and runoff damage "is most easily achieved if stormwater management starts at the point that water contacts the earth"

In the United States extensive research of the role of urban vegetation on urban water balance was carried out. According to American Forests (2004) city public works departments spend millions of dollars annually on stormwater retention facilities. By reducing peak flow that occurs immediately following storm events, urban tree canopy is a less utilized but integral component of a successful stormwater management system.

According to MacDonald (1996) in Milwaukee (N 43°), where urban trees cover about 16 per cent of the city, trees reduce stormwater flows by 22 per cent. The city saves an estimated $15.4 million by avoiding the construction of additional retention capacity. In Austin (N 30°), heavy rains make stormwater management also an important issue. Austin's tree canopy almost twice that of Milwaukee's at approximately 30 per cent, reduced stormwater flow by 28 per cent, providing the city with an estimated $122 million in savings.

Similar to solar radiation (see chapter 4.1.1) precipitation is partly and especially during the beginning of a stormwater event

Fig. 6.15: Permeable pavements: grass pavers (above) and permeable paver (below)

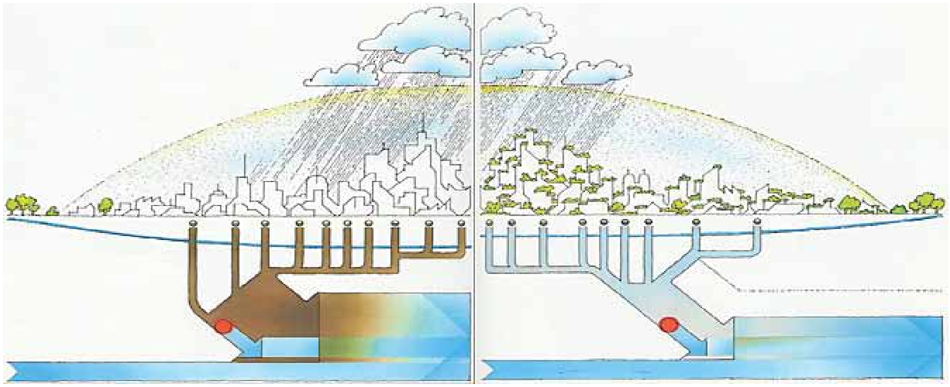


Fig. 6.16: The impacts of urban vegetation on an improved stormwater management are reducing the runoff by increasing retention and improved water quality through filtering on leafs and soils

attenuated, which means that is retained on leaf surfaces and branches and conducted towards the stem (stem-fall) and the roots and drained. Depending mainly on leaf area and canopy density respectively the fraction which is not retained intercepts to the ground (through-fall). American Forests (2004) affirm that vegetation decreases stormwater-runoff by retaining rainwater on it's leafs delaying the infiltration to the urban sewerage system through drip off.

The water balance of vegetation corresponding to a unit value can be described as the rain gauge equal to evapotranspiration, retention, superficial runoff, infiltration and water storage inside the plant. Evapotranspiration defined as the sum of evaporation (from water bodies, soils, leafs) and the transpiration from plants and difficult to measure due to high tempo-spatial variations.

6.3.1.1 Modelling Method

According to American Forests, (2004) the Urban Hydrology for Small Watersheds model TR-55[18] (developed by the USDA Natural Resources Conservation Service, NRCS) is incorporated into the program CITYgreen; The TR-55 model was designed to analyze runoff patterns during a typical 2 year, 24-hour single storm-event and includes also a water quality model.

The model assesses how land cover (and thus vegetation cover), soil type, slope, and precipitation affect stormwater runoff volume, time of runoff concentration, and runoff peak flows. It determines runoff volume

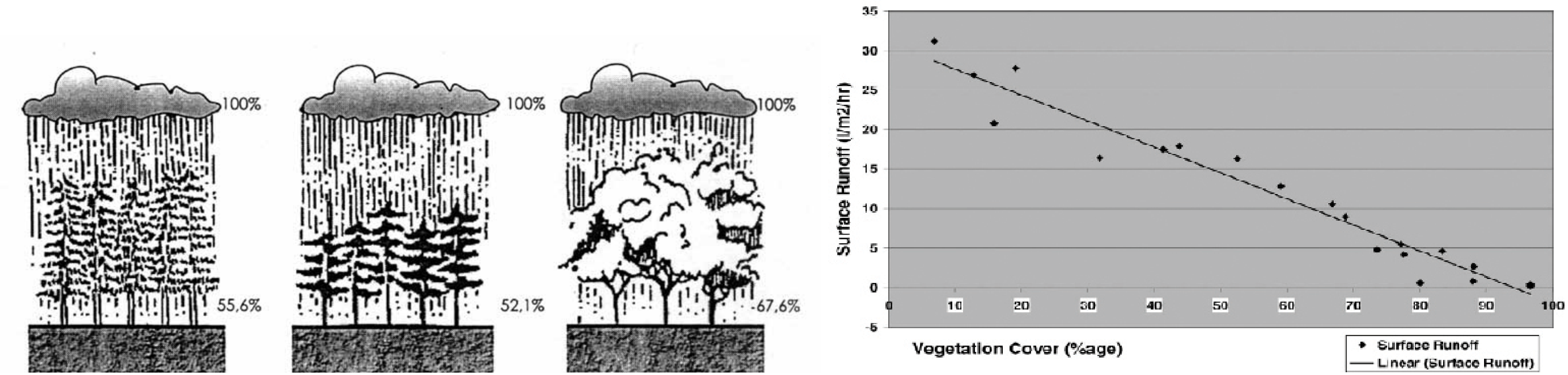


Fig. 6.17: Impact of the vegetation cover on through-fall of Chameecyparis lawsoniana, Pinus negra and Wuerus rubra (Robinette, 1972 in Mascaró, 1996 p. 81) The relationship between surface runoff and percentage vegetation by Ong (2003) based on data extracted from Pauliet and Duhme (2000).

[18] http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html <access on 29th of June 2009>
[19] According to a telephone interview on 19th of June 2009 with DAEE - Departamento de Águas e Energia Eletrica (www.daee.sp.gov.br) <access on 29th of June 2009>

based on the percentage of tree canopy, local rainfall patterns, soil type, and other site characteristics. Land cover percentages are then combined with average precipitation data, rainfall distribution information, percent slope, and hydrologic soil group.

The TR-55 calculations are based on curve number which is an index to represent the potential for storm water runoff within a drainage area. Curve numbers range from 30 to 100. The higher the curve number the more runoff occurs.

The program calculates the volume of runoff that would need to be contained by stormwater retention basins if all vegetation was removed. This volume multiplied by local construction costs for stormwater facilities, calculates a dollar value saved by onsite tree canopy.

Test simulations showed highly sensible responses to three main indicators (responsible for the dimensioning of retention facilities for the mean maximum rainfall case): Vegetation cover, the magnitude of a typical 2-year 24-hour storm event and the average construction cost per cubic meter urban stormwater facility (such as *french drains,* see fig. 3.33). The mean local construction cost of R$ 70 per cubic meter (US$ 35.89) for additional stormwater storage was given by the public relations department of DAEE[19]

Raintype and Precipitation

CITYgreen links local canopy information with national spatial datasets (geodatabases) only available for the U.S. yet. To adjust raintype (and precipitation volume of a typical 2-year 24-hour stormwater event) regional shapefiles had to be added above the São Paulo region in ARCGIS. For the raintype parameter, a regional shapefile providing the classification Raintype III (which represents coastal areas where tropical storms lead to typical torrential 24-hour rainfalls) was added.

Peak 24hr stormwater events in São Paulo during the last two decades (according to Cenofanti and Brancatelli, 2006) have already reached maxima of 151mm (on 21th of December 1988) and 140.4mm (on 24th of May 2005) and are well documented. The specific indicator of a typical 2-year 24-hour stormwater event required by CITYgreen is more difficult to acquire e.g. due to strong variations within the municipal area.

According to CGE (Centro de Gerenciamento de Emergéncias) the most intense rainfalls within São Paulo"s municipal boundaries occur in the áreas were land sealing and urban heat island are strongest and vegetation indices lowest. According to expert information (see also São Paulo media information after the storm event of 8th of September 2009 and Meteonorm standard precipitation data for São Paulo) 72mm - with rising tendency – can be assumed here and were backed as a regional shapefile in the CITYgreen model. Further as additional input information "Very impervious soil" was chosen as default (only used to calculate runoff when no other information available for the grid) because it represents the properties of the urban region best. Also considered by CITYgreen in the calculations is raster topography DEM-model to calculate the curve number and runoff.

6.3.2 Air Pollution Removal

Urban vegetation has various positive effects on the masses of atmosphere (especially close to the canopy) but especially its capacity of air pollution removal is often overestimated. Generally cooler temperatures (generated by vegetation shade and evapotranspiration) reduce air pollution and smog, and leafs themselves absorb air pollution (gases and particulate matter). The latter tend to adhere and settle down instead of being swirled around by turbulence close to vegetation.

The negative impacts (or drawbacks of vegetation) located in places with very high pollution indices (e.g. b*us rapid transit* corridors) is that the roughness of the vegetation canopy can decrease the dispersion of the pollutants, especially when winds are low and urban thermal inversions occur due to the urban heat island (an the location in a valley) so that pollutants remain trapped below (especially dense canopies) and pollution levels (especially ozone) increase, which is why the greenest districts and parks of São Paulo can be the most polluted regions of the city during the summer (Destak Editorial, 2008).

Fig. 6.18: Air pollution reaches health-endangering measures especially in the dry winters (above) and leads to increased respiratory problems within the population (below)

[20] based on data from the National Institute of Meteorology and the Center for Emergency Management

However the general benefits of vegetation to absorb gases and particulate matter from the surrounding urban air mass (or atmosphere) remain unquestioned, especially because other methods which could substitute vegetation here are sparse.

The emissions caused by vehicles burning fossil fuel is (also in São Paulo) slowly being recognized as the main obstacles to render cities more sustainable and livable and that this problems needs to be attacked in of big cities worldwide and in particular in tropical metropolises. Aside from air pollution also soil sealing, noise emissions, exposure of pedestrians and (direct) traffic deaths etc. are important issues linked to individual transport.

Actually the are only few strategies to solve the severe problem of bad air quality in cities:

- Cleaner burning of fuels (e.g. through the emission control vehicle inspection)
- Alternate fuels, like alcohol or hydrogen
- Fostering of public transport, which is the most indicated solution but on the other hand diesel buses in São Paulo e.g. would need to become a lot cleaner. According to Viera (2007) in São Paulo 70% of the surveyed citizens by Ibope would change from individual car to public transport if it was better developed.
- Fostering individual bicycle locomotion is another highly sustainable solution for which an integrated cycle path network of green corridors (linear parks) which should be developed. In tropical environment shade trees to generate thermal comfort to lower the metabolite rate play a crucial role for such development. However the hilly topography of São Paulo demands an integrated citywide planning e.g. along level curves.
- Planting urban trees to absorb the emissions

6.3.2.1 Dispersion of Pollutants

Emissions of air pollutants, air circulation and the dispersion and absorption of the pollutants is a highly complex issue which must be considered when planting urban trees in a proper way is carried out. These aspects can be treated here only in a resumed way.

One drawback with trees (in hot climates also on thermal comfort) is that they block the wind; a deciduous tree may reduce wind speeds by 30-40% (Ali-Toudert and Mayer, 2007). Contradictory it was found by means of microclimate simulations that wind-speeds increase below isolated trees (see chapter 6.2.1).

The decrease of the dispersion of pollutants through vegetation wind obstacle were analysed by Santos et. al. (2004) and Bruse (2002) using ENVI-met. Especially on greened large avenues (or bus corridors) with strong pollutant emissions from cars and in garden neighbourhoods with dense vegetation canopies high concentrations especially of ozone can occur, which indicates the importance of restricting the density of urban vegetation canopies (as well as the fluxes of vehicles).

6.3.2.2 Modelling Method

According to American Forests (2004) urban trees perform a vital air cleaning service that affects the well-being of urban dwellers. The software estimates the absorption and filtering of nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10), (as well as CO_2 in another module, see following chapter) through vegetation cover or leaves respectively.

In order to calculate assign a monetary values for these pollutants, economists calculate according to American Forests (2004) “externality” costs, or indirect costs (see chapter 5) borne by society for rising health care expenditures and reduced tourism revenue. For this study it needs to be pointed out, that the actual externality costs for various air pollutants are set in the U.S. by the Public Services Commission in each state, which means here the state of California because as a reference (“surrogate”) city Los Angeles is chosen as a hot and most air polluted city in the U.S.

CITYgreen’s *Air Pollution Removal Module* is based on research conducted by Nowak (2003, unpublished), who developed a methodology to assess (or better estimate) the air pollution removal capacity of urban forests with respect to pollutants in 55 U.S. cities, depending forest canopy coverage on the site and on the urban forest structure.

The methodology determines a pollutant removal rate or flux by multiplying the deposition velocity by the pollution concentration. The pollutant flux is then multiplied by the area of the surface over periods in which the pollutant is known to exist over that surface in order to estimate total pollutant flux by hour for that surface. Hourly fluxes can be summed to estimate daily, monthly, or yearly fluxes. Currently, air pollution estimates generated from CITYgreen are designed for urban and suburban forests.

The megacity of Los Angeles (California), - rated the most air-polluted city in the United States - was chosen as reference/ surrogate city for the calculation of removal of pollutants in São Paulo because it is assumed that its indices best represent (although even underestimates) the high pollution indices in São Paulo. Another argument for this choice was that Los Angeles is a subtropical climate of the city, which is, as recommended by American Forests (in their yet unpublished paper *International Users’ Guide for CITYgreen)* also crucial when it comes to choosing a reference/ surrogate city that matches for the air pollution removal calculations.

[21] UNEP/ UN-HABITAT (2006) Climate Change-The Role of Cities - http://www.unhabitat.org/pmss/getPage.asp?page=promoView&promo=2226 <access on 30th of June 2009>
[22] www.iniciativaverde.org.br <access on 30th of June 2009>
[23] Data resumed in http://www.urban-age.net/0_downloads/pdf_presentations/SaoPaulo/_conf/022_EduardoJorge.pdf <access on 30th of June 2009>

6.3.3 Carbon Sequestration and Storage

Although the impact of atmospheric carbon dioxide (CO_2) on climate change is still discussed its impact on temperature increase is considered "very probable". Carbon dioxide is considered a heat-trapping greenhouse gas, which absorbs infrared radiation and is capable to alter global climate[21]. Its rather homogeneous concentration, accumulated and increasing in the Earth's atmosphere is traced back to the global human activities of burning of fossil fuels, since the beginning of the industrial revolution, to deforestation and land-use change (also due to urbanisation) worldwide and increased from 300ppm to ca. 385ppm since the beginning of the industrial revolution.

There are only five prime ways to reduce the effects of global warming resumed (among others) by the Brazilian NGO (non-governmental organization) *The Green Initiative*[22]:

- Replacing fossil fuels by renewable sources (e.g. by burning the methane greenhouse gas emitted by landfills, like São Paulo's *Aterro das Bandeirantes*, to produce energy).
- Increasing the efficiency of energy and water consumption
- Subterraneous storage of compressed CO_2, (although a doubtful solution)
- Reduce deforestation and reforestation of degraded areas

The Brazilian Nation is a major CO_2 emitter, which annually "exhales" 49 billion tons of greenhouse gases (published by the Ministerio da Ciência e Tecnologia, 2002) and ranks internationally on the 8th position, of the nations with the highest greenhouse emissions behind Germany (ISA, 2008).

Different from (so-called) developed industrial countries in Brazil nationwide the larger part of CO_2 emissions is assigned to (slash-and-burn) deforestation and land-use change, (70%) and to a much lesser part to energy consumption (30%) (Houghton *et. al*. 2000).

In the context of (mega-)cities this relation inverts due to elevated energy consumption for mainly transportation, illumination and cooling buildings etc. According to an inventory on the emission of greenhouse gases of the City of Sao Paulo (SVMA, 2007[23]) 15,738,241 tons of CO_2 were emitted in the year 2003 (Carranca, 2007). In 2007 the Estado de São Paulo published an estimate of 32,548,000 tons for the year 2008.

In contrast to the national emissions most of the urban emissions are provoked by energy use (ca. 75%) mostly burning fossil fuels and waste (ca. 24%). According to the report less than 0.5% (51,000 tons) are results of changes in the soil and forest utilization within the municipal area of São Paulo.

According to Carranca (2007) an average of five to seven annually planed trees is considered by Brazilian NGOs and firms which neutralize carbon footprint. Emissions of 2.07 tons per year, for a middle class resident in São Paulo are equivalent to ca. 14 new trees per year. On a citywide scale 80 - 220 million trees needed to be planted annually to neutralize the megacity's carbon footprint.

However as a comparison the global mean annual emission also *called carbon footprint* is according to Wacknagel and Rees (1992) circa 7 tons of CO_2 but depends highly on life style and consumption which highly varies especially in cities like São Paulo and/ or countries like Brazil.

Protocol of Kyoto

In 1997, five years after the 1992 summit in Rio de Janeiro, the majority of the global community's leaders signed the *Protocol of Kyoto* which's aim is to decrease carbon footprint and emissions of atmospheric greenhouse gases (such as carbon dioxide) stepwise to mitigate global climate change, but until today global carbon emissions are still increasing constantly.

Again different from some developed industrial countries, located in the temperate climates, in emerging tropical countries like Brazil more heat and outcomes of global heating which are difficult to predict must be considered highly undesired (see Lovelock, 2006). Especially in cities the overlay of (greenhouse) effects leads to the clearly negative impacts described in the preceding chapters.

Emerging and developing countries, like Brazil, not have obligations to limit their emission limits during its first phase of the *Protocol of Kyoto* (2005-2012), developing and threshold/ do but have ratified the protocol due to the interesting business options of being allowed to trade carbon credits, generated by avoiding or sequestering carbon emissions elsewhere.

6.3.3.1 Trading Carbon-Offset with urban Trees

In Brazil voluntary large-scale tree planting programs mainly in non-urban degraded areas of the *Atlantic Forest* are replanted with native vegetation by NGOs like *Green Initiative, SOS Mata Atlântica*[24] etc. (in some cases in combination with bank initiatives). These are considered legitimate tools in the national carbon reduction program. According to McHale *et. al.* (2007) CO_2 sequestered by urban trees can also be traded but the success of such programs depends on urban forest management, latitude and the future price development of the sequestered carbon on the market.

A drawback was shown by studies conducted by Nowak, McPherson and others (1994) which indicate that if urban trees are properly maintained over their lifespan, the carbon costs outweigh the benefits. This is because tree maintenance equipment such as chain saws, chippers and backhoes emit carbon into the atmosphere. Carbon released from maintenance

[24] http://www.sosmatatlantica.org.br/ <access on 30th of June 2009>

equipment and from decaying or dying trees could conceivably cause a carbon benefit deficit if it exceeds in volume the amount sequestered by trees.

To maximize the carbon storage/ sequestration benefits of urban trees, American Forests (2004) suggest to plant large and long living (non-pioneers, initials and climax) species in urban areas, so that more carbon can be stored, mortality rates can be decreased, and maintenance methods can be revised over time as technology improves.

Carbon Storage and Growth Rates

According to American Forests (2004) trees remove carbon dioxide from the air through their leaf stomata and metabolism/ sequestration rate, which highly depends on the succession of individual plants and varies widely. In quantifications *carbon storage* is the total amount of carbon held in a tree's wood (biomass) until the decomposition of the wood (lifecycle) and *carbon sequestration* is the rate at which trees store. The conversation constant between sequestered CO_2 and stored carbon in tC/ ha vegetation cover is 3.67.

Generally older trees have more carbon storage and younger trees a higher sequestration rate. As mentioned only 0.05%-0.25% of the absorbed photosynthetically active radiation (PAR) is transformed into biomass while the rest is used to transform liquid water into water vapor to stimulate the photosynthesis/ evapotranspiration process. Approximately half of a tree's dry weight is carbon, the rest glucose, fats etc. and the wood density (specific density) is an indicator for succession, storage and sequestration rate.

According to Ong (2003) conversely, Karlik and Winer (2001) studied biogenic emissions of plants (BVOCs) that contribute to the production of ozone and other photochemical compounds and hence promote pollution rather than reduce it. Ong (2003) points out that the authors found that these emissions are characteristic of certain plant species and the amount emitted is linked to leaf mass, the formation of ozone and air temperature.

6.3.3.2 Modelling Method

According to American Forests (2004) the program estimates the carbon storage capacity (annual carbon sequestration rates) of trees as well as carbon stored within a defined study area. The carbon module multiplies a per unit value of carbon storage by the area of canopy coverage and reports in tons. The method does not assign monetary values and American Forests (2004) recommend whatever local valuation method the user feels appropriate.

Users can also adjust the calculation to local estimations by entering weight of stored carbon and annual rate of carbon sequestration per unit of canopy in grams per square meter. Testing this function it was found that the CITYgreen results (derived from trees at different growth stages in the U.S.) showed storage and sequestration rates that meet conservative estimations given by Martins (2004) for local vegetation in São Paulo state.

It must be pointed out that mean values of storage and sequestration per unit forest cover represents only a rough guideline value due to the strong variations (species) and of the environmental conditions (e.g. water and nutrient availability, location etc. of vegetation cover) and that there is a lack of more detailed information on growth rates, carbon sequestration and storage for isolated urban trees in São Paulo at this moment.

Generally it can be assumed that in the (sub-) tropical Brazilian *Atlantic Forest* biome the CO_2 sequestration rates are higher than in the deciduous forest biomes of the temperate climate regions due to climate, an all year growth period and mostly evergreen and semi-deciduous vegetation, but research on CO_2 sequestration and growth rates is more advanced in the northern biomes. Especially the lianas and creepers of the *Atlantic Forest* biome grow faster and sequester CO_2 more rapidly than trees of the biome because their wood architecture is limited.

Typical species of the (sub-) tropical *Atlantic Forest* biome are divided into three *ecological groups* by biologists according to their succession, which refers to growth and CO_2 sequestration rate (see fig. 4.6). According to Kajeyama and Gandara (2000) the mechanism of succession is responsible for the self-renovation of tropical forests, promoting the healing of disturbed areas.

- **Pioneer species** are fast growing species with high sequestration rates and short lifespan of 5-10 years. According to *Green Initiative* these species develop well exposed to sun. In natural regeneration or in reforestations these species create shade conditions that are essential to the development of the species of posterior stages of succession (Non-pioneer).

- **Initial secondary species** have a mean growth rate with mean sequestration rates and a life-span of 15-20 years and are shade-resistant in contrast to the pioneers which develop better when exposed to sun.

- **Late secondary species and climax species** have low growth rates, low sequestration rates and grow better under shade conditions. According to *Green Initiative* there is a large number of these species which are responsible for the diversity of the Atlantic Forest biome. Not all of the species are proper to be planted on side walks as street trees.

7. RESULTS AND DISCUSSION

The large variety of costs and benefits introduced and discussed in chapter 5 shows that a complete cost-benefit analysis of São Paulo's urban vegetation is virtually impossible. The quantification is difficult due to the state of research (data and models) and monetisation of the benefits is both controversial[1] and difficult, because it depends on auxiliary comparison models to estimate the avoidance of damage etc. In the following the results (estimations) of the environmental benefits (see chapter 5.3) derived from modeling are presented and discussed. It is pointed out that all estimates are concerned *conservative estimates* which tend to rather underestimate than overestimate. The social benefits (outlined in chapter 5.3.2) remain neither quantified (nor monetarily valorized) because they are considered benefits beyond conceivability or immeasurable.

7.1 Results

7.1.1 Thermal Comfort and Energy Conservation

Within different urban structures great tempo-spatial variations in terms of thermal comfort (or stress and *perceived temperature* TEP) were simulated. It was found that the distinct spatial variations of direct solar radiation and shade are principally responsible for the variations of thermal comfort while air temperature, humidity and speed are less significant indicators.

In outdoor environments the local *perceived temperature* (TEP or PET) depends rather on the complex and changing overlay of shading patterns of buildings, trees and other obstacles than on the actual ambient air temperatures. Stepping out of shaded areas into sunlit areas (were the air temperature is the same as in the shade) on clear days results in tropical latitudes in an abrupt decrease of thermal comfort and an increase of heat stress.

This means that comfortable zones are actually visually recognizable especially during the summer due to *shadowplay* (darker, cool zones) and is comprehensible empirically and probably influences decisions were to circulate in open, public spaces (see dPET, chapter 6.2.1.1).

During the midday hours of the summer months, with no or little obstruction by clouds and with high solar inclination and magnitude building shades loose their positive impact on comfort that they have in the morning and as well in the afternoon. During these hours - which represent the peak hours in terms of thermal discomfort - typical urban geometries and the users of the public space receive strong vertical radiation which heats up skin and cloths immediately, causing discomfort. Due to multiple reflection sunrays get trapped in street canyons and heat up their surfaces.

Combining the database for tree canopies (see table 4.2) with approximately calibrated micro- and macro-scale climate data for the typical summer day allowed experiments combining both scales allowing estimations of the magnitude of thermal comfort, pointing towards energy efficiency. Definitive statements which allowed assigning a monetary value to thermal comfort remain future work, mainly due to unavailability of a model at this moment. However a general guideline estimation per tree will be assumed at the end of the chapter.

Tendencies

The impact of a single urban tree canopy (density LAI 4) on thermal comfort (TEP) at mirco-scale was visualized carrying out a high resolution ENVI-met study (with improved version 3.1 Beta II, 2009). On the typical summer day 19th of December at 15h (with air temperature of 32ºC, relative humidity of 40% and wind speed of 0.8 m/s) the simulated perceived temperature below the tree was 8.69ºC lower than in the direct sun aside of the crown, while the air temperature varied only 0.1ºC, humidity by 5% within the model domain. The wind speed was also influenced only slightly and was increased below the single tree crown, proliferating comfort slightly.

Another interesting finding is, that the comfort above the canopy improves slightly (TEP decreases) due to the high fraction of absorbed radiation and the low fraction of reflected radiation.

It is remembered that here all impacts of the crown on micro-climate and thermal comfort are simulated (including evaporation cooling) since McPherson and Simpson (1995) had pointed out that the shading effect can easily be estimated for a single tree, while the cooling by evapotranspiration is more difficult to assess because the fresh air generated is

[1] The monetisation of the benefits can lead e.g. to the commoditization of the tree itself, as discussed by some authors

rapidly diffused in the air volume which traverses the tree crown. It was found that the simulated positive effect (of ca. 0.1°C) on the lee-side of the crown is negligible for single trees.

In the following the impact of tree canopies (10m height and diameter) on surface temperature (dry asphalt), mean radiant temperature (MRT), daylight levels, sky view factor and perceived temperature (TEP) was analyzed below LAI 1 (very light crown) to LAI 10 trees (very dense crown) at 1.5m height and at solar noon (13h, local time with vertical solar incidence). The results show that all indicators decrease with increasing canopy density according to natural logarithms.

These results underline and quantify the benefit of tree-shade on thermal comfort but do also show the rapid decrease of daylight levels below very dense crowns which can (close to buildings) lead to increased energy consumption for artificial lighting (see chapter 5.2.2 and 6.2.2.2).

The differences per increase in leaf area index show that the strongest increase of comfort can be achieved with low leaf area indices, while the benefit decreases with higher LAIs according to the critical relation between daylight access and heat load. The results show that while mean radiant temperature (crucial for comfort) decrease by 15ºC, luminance decreases to low levels below very dense canopies of less than 300 lux at midday below very dense canopies.

Although the logarithmical relation varies with for example with leaf albedo and crown shape (assumed here was an extinction factor of 0.5) and solar angle (daytime), the relation presented above shows a mean approximation of the relation between crown density and shade coefficients.

Another study analyzes the daily variation of thermal comfort (applying PET calibrated to São Paulo conditions by Monteiro and Alucci, 2007) in a typical narrow street canyon in Luz with no vegetation cover (actual situation) and two tree canopies, of which one is light (LAI 1) and the other very dense (LAI 5) (see Spangenberg *et. al*, 2007)

The indicator PET indicates a maximum (perceived) difference of 12ºC between the street canyon with no shading element and a dense LAI 5 tree and 8°C between no shade and light density tree. Generally the trees are overhead shading elements mitigating thermal stress significantly making peak heat stress situation more tolerable. Their effects are important especially between 11h and 16 h in the summer, while (depending on verticalisation) building shade generates comfort before and after the midday period of thermal stress.

The results show that peak thermal discomfort on 19th of December tends to occur in the afternoon at around 15h when direct radiation still penetrates the canyon, when the surfaces are heated

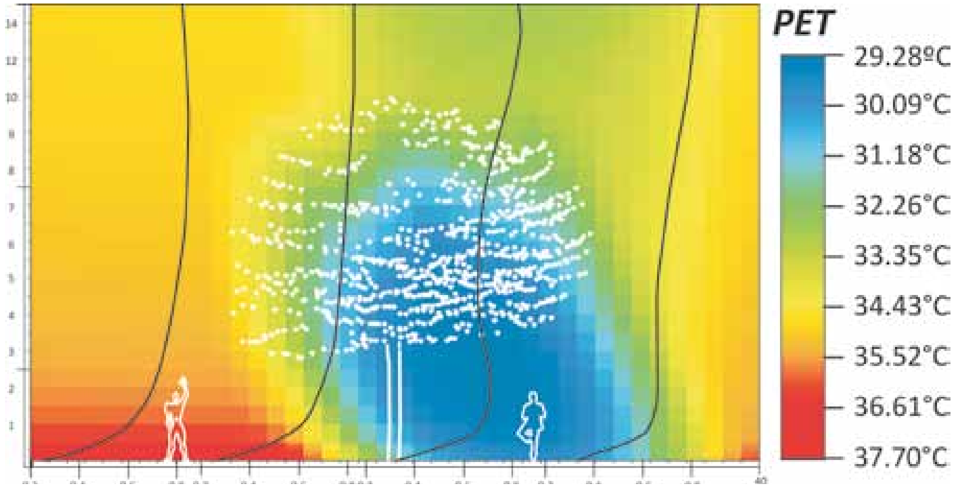


Fig. 7.1: The attenuation of direct solar radiation by the tree leads to increased comfort and lowered TEP quantified here for 15h air temperature 32°C, humidity 40%, speed 0.8 m/s

LAI [unitless]	Surface [°C]	MRT [°C]	Direct Shortwave Radiation [W/m²]	[Lux]	SVF [unitless]	TEP [°C]
0	44.41	46.88	700	65800	1.00	39.05
1	39.77	40.51	424.56	39909	0.74	35.75
2	36.28	36.13	247.39	23255	0.58	33.49
3	34.93	34.00	164.16	15431	0.48	32.39
4	33.44	32.11	93.76	8813	0.40	31.41
5	32.65	31.09	56.87	5346	0.35	30.88
6	32.16	30.48	35.01	3291	0.32	30.57
7	31.84	30.08	21.23	1996	0.30	30.36
8	31.62	29.84	12.75	1199	0.28	30.23
9	31.48	29.68	7.62	716	0.26	30.15
10	31.32	29.35	4.74	446	0.26	29.98

LAI [unitless]	Diff Surface [°C]	Diff MRT [°C]	Diff Direct Shortwave Radiation [W/m²]	[Lux]	SVF [unitless]	TEP [°C]
0-1	4.64	6.37	275.44	25891	0.26	3.29
1-2	3.49	4.38	177.17	16654	0.17	2.27
2-3	1.35	2.13	83.23	7824	0.10	1.10
3-4	1.49	1.89	70.40	6618	0.08	0.98
4-5	0.79	1.02	36.89	3468	0.05	0.53
5-6	0.49	0.61	21.86	2055	0.03	0.32
6-7	0.32	0.40	13.78	1295	0.02	0.21
7-8	0.22	0.24	8.48	797	0.02	0.12
8-9	0.14	0.16	5.13	482	0.01	0.08
9-10	0.16	0.33	2.88	271	0.00	0.17
Mean	**1.31**	**1.75**	**69.53**	**6535**	**0.07**	**0.91**

Table 7.1.: Simulated impact of LAI 1 to LAI 10 canopies on thermal and luminous quality below the canopies, the perceived temperature lowers by one range from hot to slightly hot (p. 141) Difference per increase leaf area index (above)

up and the air temperatures reach their maxima. Additionally it was found that because of the lower solar angles larger parts of the bodies of users are exposed to direct radiation than at midday, when only head and shoulders are attained.

In the following the same climatic conditions of the 19th of December were tested for six parameterized typical urban tissues (150 x 150m each) with different spacing, building heights, population densities, with and without vegetation cover (LAI 3) and consequently different sky view factors. Further all tissues were all rotated 45º out of the North-South-Axis, to visualize and maximize the benefit of building shade (and its limitations).

The original tissues which inspired the parametric surrogate tissues distributed throughout the central region of São Paulo. The respective citywide RAMS results (see fig. 6.7) were combined with the local ENVImet simulation data to calculate TEP.

It should be pointed out that only ca. 9% (see fig. 6.13) of the municipal area are represented by urban tissues with vegetation cover (right), while those with no or sparse vegetation represent more than 50% of the municipal area (left) (see fig. 6.13). The distribution of pleasant and unpleasant places (in terms of thermal comfort) of the morphologies shows, that the tissues with tree covers are perceived climatically considerably more modest by more (perceived temperatures of 35ºC at peak hours instead of almost 50ºC) underlining the benefits of vegetation to mitigate stress due to overhead shading.

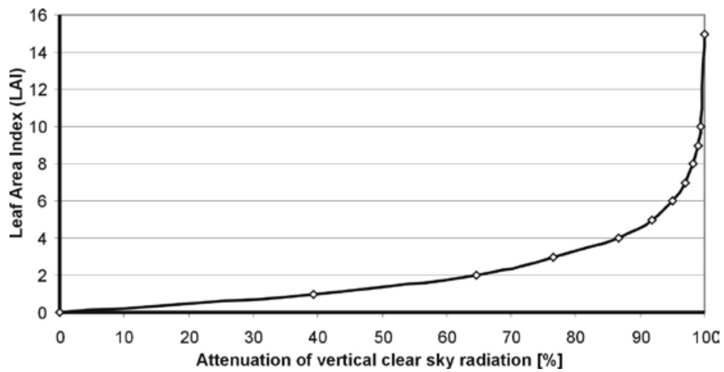
The study shows that the microclimate of a place (and thus its thermal comfort) highly depends on its sky view factor (SVF) especially in predominantly hot climates were thermal and discomfort comfort is determined by radiation during daytime. Especially during summer midday when maximum heat stress occurs small sky view factors increase thermal comfort (while large sky view factors decrease thermal comfort.

It was further concluded that the climatically most adapted urban form (at least during the summer) is the *Jardim Paulista Neighbourhood* (due to the overlay of tree shading plus overshading of the buildings). Interestingly this typology is also the one with the highest potential population density and can thus be considered a sustainable form which offers qualified density.

Although this typology could be the one which generates most cold stress during the short winter (which could be mitigated by planting deciduous trees) the aforementioned follows the strategy necessary for predominantly hot and sunny climates of tropical latitudes.

To estimate the time frames in which vegetation cover improved thermal comfort in São Paulo a modified version of the software URBCON 2010 (based on

Fig. 7.2: The relation between Leaf Area Index (LAI) and the attenuation of the vertical solar radiation at solar noon (zenithal angle) under clear sky conditions (direct radiation > 85%).



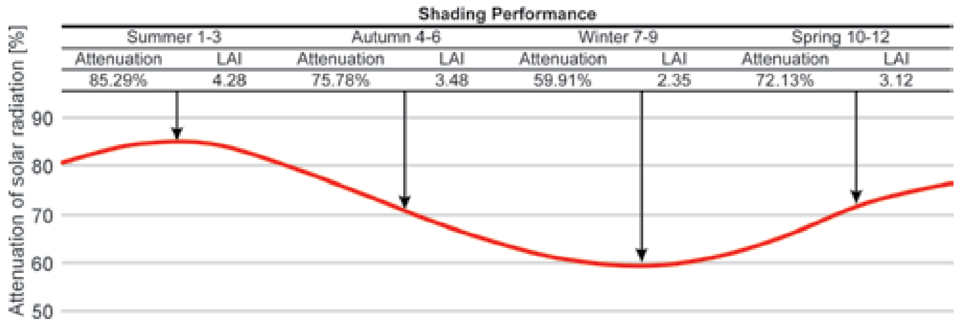


Fig. 7.3: Interpolated mean semi-deciduousness (of the local Atlantic forest biome, derived from master plant database, table 4.2) shows that LAI tends to oscillate throughout the year between LAI 2.35, attenuation of 59.91% in winter and LAI 4.28, attenuation 85.29% in summer

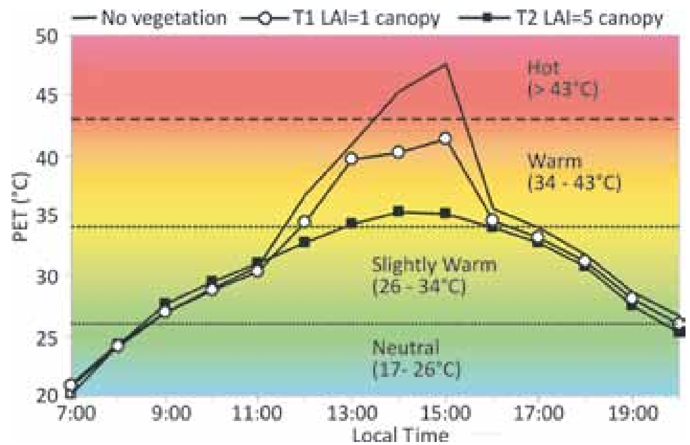


Fig. 7.4: Daily variation of thermal comfort without, below light and below dense vegetation covers

Tensil 1.2 by Alucci 2005[2]) was applied. The program simulates the thermal indicator *Heat Load* (Blazejcyk, 2002) in local outdoor situations for 12 typical monthly days below open sky, fabrics (tent roofs). As pavement concrete was chosen, and a standing person as user, which is using mean albedo cloths (“intelligent user”)

The calculation using the comfort indices (HL and STI) did not represent the effects of tree canopies on thermal comfort precisely. Since the microclimate simulations showed an increase of thermal comfort below mean density tree canopies by one interpretation range – this empirical result was visualized for a typical year.

The estimated differences of heat load (during 4380 annual daylight hours) between an open urban location and a location covered by a mean semi-deciduous tree (10m height and 10m diameter) indicate that heat stress below trees is mitigated during ca. 1885 hours per year (21.5%) from hot (H) to neutral (N) increasing neutral daylight hours from 25% to 65%.

During peak heat stress hours (occurring in ca. 17% of daylight time) very hot (VH) sensations are mitigated to hot (H) sensations while it is assumed that trees have little influence on the increase of thermal stress during very cold (VC) cold (C) periods which occur in São Paulo usually when the user receives no direct radiation because the sun is close to or below the horizon.

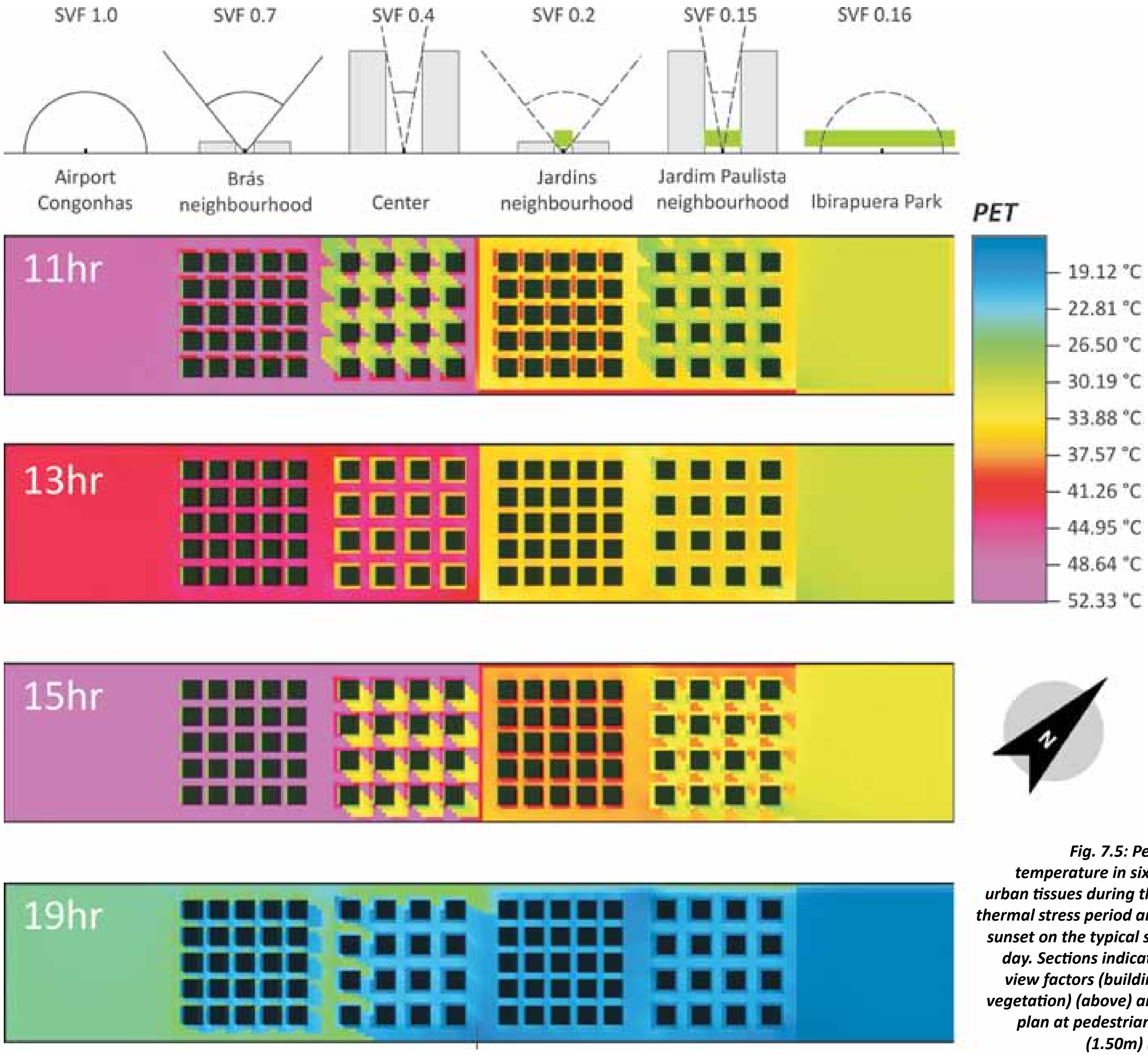


Fig. 7.5: Perceived temperature in six typical urban tissues during the peak thermal stress period and after sunset on the typical summer day. Sections indicating sky view factors (buildings and vegetation) (above) and floor plan at pedestrian height (1.50m) (below)

[2] Tensil 1.2 - Coberturas têxteis: determinação das características térmicas e luminosas Online: http://www.usp.br/fau/pesquisa/laboratorios/labaut/conforto/index.html < access on 01st of July 2009>

Yet another direct benefit of trees is increased natural thermal comfort *inside* of buildings, which leads to decreased cooling loads, cooler building surfaces and thus less (or no) energy consumption for the cooling of buildings located close to (or below) canopies.

Trees are (according to American Forests) most effective when located to shade air conditioners, windows, or walls and when located on the side of the building receiving the most solar exposure (maximum shade). The west side is indicated as the most valuable, followed by the east. In the Southern hemisphere/ Brazil however not the south side (like in the Northern hemisphere/ United States) but the north side is more recommended than the south side, were planting should be avoided.

Thus on the North side, the benefits are slightly offset by the negative effects of obstruction in the winter, so that evergreen trees should not be planted on north sides in São Paulo. Further McPherson and Simpson (1995) mentioned that two trees are about five times more effective than one isolated tree and that one tree located for shading a west facing wall is as efficient as two identical trees on the east pointing out, that the optimal location of the vegetation is a crucial planning and design criterion.

Benefit and value

However to define the capacity (and value) of single typical urban tree to mitigate the local urban climate located in São Paulo increasing thermal comfort in open spaces and decreasing energy consumption in buildings further investigations are necessary, which remain future work.

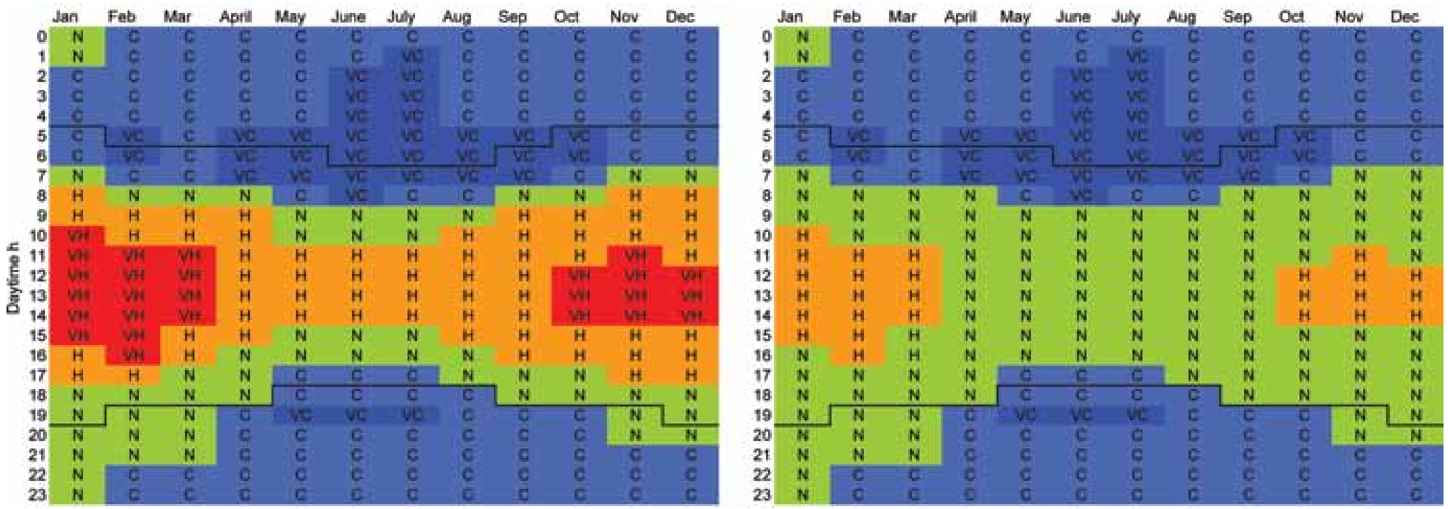


Fig. 7.6: Mitigation of heat stress: Annual analysis of heat load in São Paulo and below open sky (left) and empirical estimate below shade tree of mean density (right)

Due to the multitude of highly varying parameters within the urban fabric, especially sky view factor and leaf area and the costs to carry out a representative stratum of small area studies (e.g. with CITYgreen 5.0) an empirical approach was chosen to value the direct benefit of urban trees to regulate climate and to increase comfort and decrease energy consumption.

A value of 95 kWh per tree (derived by McPherson *et. al.* (2005) in Berkeley/ California, 37°N) is assumed here as a benchmark of energy saved per tree because the climate of the city is also predominantly hot and similar to that of São Paulo 23ºS. Since solar radiation is less intense in Berkeley (according to latitude) this means probably an underestimation of the real energetic benefits of trees in São Paulo.

On the other hand mainly greened low-rise regions, which represent only ca. 9% of the municipal area of São Paulo benefit more from shading benefits than verticalized regions but it is remembered that this also intends to valorize the benefits of increased thermal comfort in open spaces

Assuming a mean annual benefit of 95 kWh at a cost of R$ 0.29 per kWh (see Eletropaulo, 2008[3]) only for each of the 1.5 million inner city street trees (Gregório, 2006) results in a benefit of R$ 27.55 per tree and a total annual benefit of R$ 41,325,000 for all street trees, while the much larger number of forest and park trees are we not considered in this estimation, since they do not directly shade buildings.

7.1.2 Stormwater Retention

Generally urban trees decrease the total stormwater volume helping (especially tropical) cities to manage their stormwater and decrease detention costs. The CITYgreen model assesses how land cover, soil type, and precipitation affect stormwater runoff volume. It calculates the volume of runoff in a 2-year 24-hour storm event that would need to be contained by stormwater facilities if the trees were removed. The *curve number* (calculated by the model) range from 30 to 100 and are indicators for run-off. The higher the curve number the more runoff will occur. The CITYgreen simulation for São Paulo showed a high curve number of 90 for the existing land cover conditions indicating high run-off.

CITYgreen estimated the benefits of the existing urban vegetation on stormwater savings management to US$ 2,225,951,969 pointing out that an additional stormwater storage volume of 26.5 million cubic meters is needed. The annual costs for additional *french drains* based on payments over 20 years at 6% interest rates were calculated to US$ **194,068,636** per year.

Water Quality and improvement of Contaminant Loading

According to American Forests (2004) cities in the U.S. must comply with Federal clean water regulations and develop plans to improve the quality of their creeks, streams and rivers. Trees filter surface water and prevent erosion, both of which maintain or improve water quality. In Brazil similar regulations are due to be issued within the next decade.

CITYgreen using values from the US Environmental Protection Agency (EPA) and Purdue University's L-thia spreadsheet water quality model, American Forests developed the CITYgreen water quality model. The model estimates the change in the concentration of the pollutants in runoff during a typical storm event given the change in the land cover.

The model estimates the Event Mean Concentrations of Nitrogen, Phosphorus, Suspended Solids, Zinc, Lead, Copper, Cadmium, Chromium, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). The pollutant values are shown as a percentage of change.

The promising results show, why an integrated stormwater management and environmental planning which considers

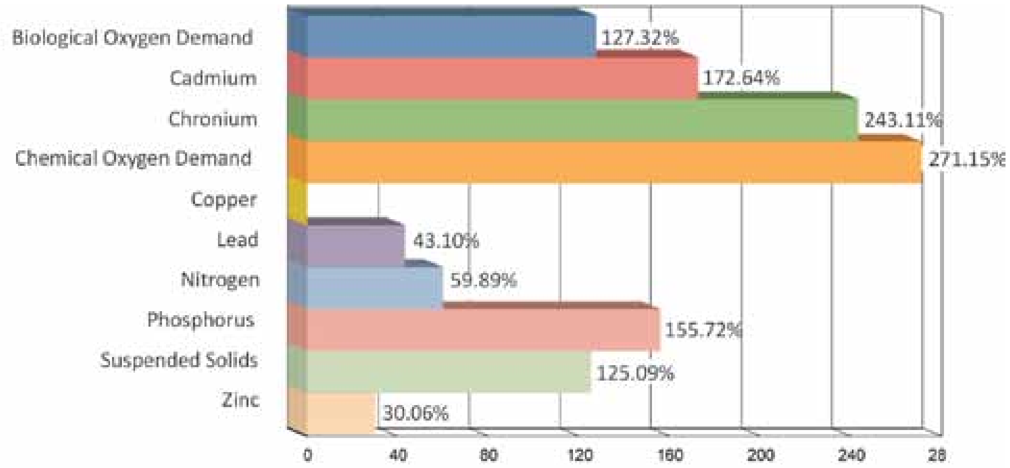


Fig. 7.7: Percent Change in Contaminant Loadings

Fig. 7.8: Some literally green designs have been proposed to transform São Paulo's river banks into more attractive and accessible for public use and infiltration areas again, see Master Plan Strategies-Reconstruction of Marginais by Leite/ Spadoni (2002) and "Reflooding São Paulo" by Sagree Sadia (2006)

[3] http://www.eletropaulo.com.br <access on 01st of July 2009>

vegetation as purifier of the basic needs of natural resources, here soil and water (but also air respectively, see following chapter 7.1.3) is of high importance in São Paulo, especially when it comes to revising the relation between city and water bodies.

Especially on the banks of the rivers (and the reservoirs) landscape projects (in combination with sewage treatment) bear chances for important change urban, allowing accessibility and recreation as well as protection and cleaning of these resources, which have become the cloacae during the period of rapid urban growth should be revised now environmentally to secure an urban future.

7.1.3 Air Pollution Removal

By absorbing and filtering out nitrogen dioxide (NO2), sulfur dioxide (SO2), ozone (O3), carbon monoxide (CO), and particulate matter less than 10 microns (PM10) in their leaves, urban trees perform a vital air cleaning service that directly affects the well-being of urban dwellers. CITYgreen estimates the annual air pollution removal rate of trees within a defined study area for the pollutants listed below. To calculate the dollar value of these pollutants, economists use “externality” costs, or indirect costs borne by society such as rising health care expenditures and reduced tourism revenue. The actual externality costs used in CITYgreen of each air pollutant is set by the each state, Public Services Commission.

The CITYgreen results indicated that the city’s urban forest annually filters 14,676 tons of pollutants contributing to the decrease of the cardiorespiratory diseases worth $81,483,617. Especially the monetisation of the benefits, (or avoided external costs respectively) to the conditions of the Brazilian health system remains to be revised.

7.1.4 Carbon Sequestration

The mean carbon sequestration rate for São Paulo’s urban forest cover (calculated by the detailed estimations CITYgreen default model with an even tree age mix in temperate climates) showed an annual sequestration rate of 0.83 tons per hectare urban forest (tree cover), which agrees with simplified comparative calculations considering the local sequestration of *Atlantic Forest* vegetation cover within the study area of the municipal boundaries based on findings by Martins (2004). The total annual sequestration rate was thus calculated to almost 52,900 tons citywide per year.

Since this annual sequestration rate cannot be sold on the international carbon market (because it is existent and not a carbon sequestration innovation in accordance with the *Protocol of Kyoto*) its value of US$ 20 per ton sequestered, summing up almost R$ 2 million on an annual base, remains a virtual market value but as well an important an indicator for the city’s contribution against climate change. Finally it should be mentioned that the carbon stored in the (still) existing urban forest of São Paulo has a value of almost 121 million US$.

	tons	US$	R$
Carbon Monoxide:	766	720,392	$1,404,764
Ozone:	4,403	29,819,823	$58,148,655
Nitrogen Dioxide:	4,020	27,226,795	$53,092,250
Particulate Matter:	5,105	23,083,199	$45,012,238
Sulfur Dioxide:	383	633,409	$1,235,148
Totals	**14,676**	**81,483,618**	**$158,893,055**

Table. 7.1: Air pollution removal in tons US$ and R$ (considering a conversion rate of R$ 1.95)

7.2 Investments versus Environmental Benefits

This sub-chapter summarizes whether São Paulo’s investments into urban green and environment of R$ 330,403,981 in 2008 were worthwhile. The results indicate that for each Real (R$) invested at least R$ 5 return as payback as environmental benefits (or avoided damages) for sanitation and health (stormwater and air quality control), energy efficiency and to decrease the city’s carbon footprint (see table 7.2).

The results show that the municipal annual budget for tree planting and maintenance, (which increased by almost 30% between 2006 and 2007 from R$ 106 million in 2006 to almost R$ 129 million in 2007)[5], responds only to ca. 18% of the annual environmental benefits of the urban forest, and outweighs the investments by far.

Especially the improved stormwater management is the most important environmental benefit (89.3% of all benefits estimated here). Air Pollution removal however is significant, especially because it can hardly be substituted by

	Quantity	Unit	Brazilian Reais R$	US$[4]	EURO[4]	
Energy Savings for Thermal comfort	142.5	GWh	R$ 41,325,000	$22,535,787	15,294,140 €	2.3 %
Stormwater Retention	22,924,728	m^3	R$ 1,604,730,960	$875,108,908	593,901,498 €	89.3 %
Air Pollution Removal	14,676	tons	R$ 149,420,583	$81,483,617	55,299,680 €	8.3 %
Carbon Sequestration	52,867	tons	R$ 1,938,897	$1,057,340	717,574 €	0.1 %
			R$ 1,797,415,440	**$980,185,652**	**665,212,892 €**	

Table 7.2: Annual Environmental Benefits of São Paulo’s Urban Forest

[4] A conversion rates of 1.83 Brazilian Real R$ per US$ and 1.47 Euro per US$ correspond to the average exchange rate of the base year 2008 http://www.acinh.com.br/cotacao.asp and http://www.yahii.com.br/euro.html <access on 29th of August 2009>

[5] http://www.urban-age.net/0_downloads/pdf_presentations/SaoPaulo/_conf/022_EduardoJorge.pdf

other (technical) means. A pointed out before the benefits assigned to the mitigation (2.3%) of the urban heat island (energy savings and thermal comfort appear to be low (especially when compared to stormwater retention benefits) and need to be verified.

The result points out that - since the benefits of urban vegetation cover in the municipal area of São Paulo is still decreasing (especially on its peripheries due to deforestation) only at a slower rate recently – that the investments should be re-allocated and that special attention should be drawn to conservation and maintenance.

7.3 Discussion

This work shows that the efficient incorporation of urban vegetation into the existing urban environments/ fabrics/ tissues/ grids is an ambiguous and complex issue, which demands professional input e.g. from *urban foresters*, biologists, climatologists, urban planners etc.

The difficulty (and *lost link between construction and vegetation*) of incorporating urban vegetation in a strategic and functional way into built environments / fabrics/ tissues is probably why many architects see urban vegetation as a drawback (see Spangenberg 2008): As mentioned urban vegetation planted in the "right" (strategical) places can bring (unexpected and enormous) benefits in hot places, while urban green planted in the "wrong" places can cause (unexpected and enormous) damages (see Abbud, 2007).

Generally the benefits overweigh the costs and drawbacks especially in hot climates, where vegetation is unique equilibrating element (buffer), constantly cooler than building materials due to leaf evapotranspiration. Indeed urban vegetation can be designed as a technically (yet?) irreplaceable thus priceless but affordable design solution for climate adoption of hot cities.
One of the most important issues besides from maintenance and planting of urban vegetation in São Paulo is to mitigate further sprawl of urban areas into the pristine forests which are responsible for the majority of the indirect citywide benefits and can hardly be substituted by other means. The Brazilian legislation is already demanding but monitoring (for example through the analysis of satellite images) and execution control are important future aims.

Especially for the mitigation of urban heat stress during the summer (and especially during more frequent heat waves due to global climate change) trees have important (although locally strictly restricted) impacts because they decrease significantly the perceived temperature through shading (especially during summer midday and afternoons) and present a good cost/ benefit relation compared to other overhead shading elements and have further benefits to improve the quality of public spaces.

This complex task of building a green network which interlinks various scales can be carried out only if the 31 sub-municipalities of the city collaborate and with an increase the budget to maintain and to increase the vegetation cover within the municipal area as well of fostering environmental education and public policies.

This approach seeks for approximated estimations (quantifications) of the benefits of urban vegetation applying and adjusting numerical models to local conditions. The most important environmental benefits (see table 7.2) which can be resumed as reducing peaks of climatic events and tendencies, leading to an increased energy and water balance, decreased risk and well-being of the population were estimated at different scales (direct, local and indirect regional).

The results indicate that these environmental benefits of urban vegetation do already overcome the municipal investments in São Paulo by far, without even estimating the value of social benefits. The environmental benefits are higher in predominantly hot and big cities due to the intense climatic impacts (solar radiation, torrential rainfalls etc.) and can be enhanced strongly especially if vegetation is planted in the "right" places.

It was shown that the degradation of the urban environment is often closely linked to decreasing vegetation cover, which can partly be reverted by re-increasing vegetation cover (key-lock-principle). Yet it seems to be one of the main errors of contemporary thinking to take natural resources for granted and to explore them to find that they are not exhaustless in the end.

7.4 Recommendations for Urban Forest Management

In the following, the main citywide strategies for the urgent *urban forest management* interlinked with *spatial planning* for São Paulo[6] are resumed. Since local planning and execution is divided due to the size of the metropolitan area of São Paulo into 32 sub-municipalities their cooperation, especially along the political boundaries are crucial for an integrated execution of municipal aims.

Urban vegetation is a subtle or even obscure urban element because it grows rather slow, changes leafs, flowers, fruits throughout the year. Especially in the view of climate change a foresight fostering increased climate adaptation and urban sustainability is necessary but not yet part of today's vision for a future city and unclear/ obscure even in the urbanistic discourse. It is important to take plant growth into account.

It must be pointed out that urban vegetation cannot to be regarded as the solution of urban problems (discussed in this work) but that it plays a key role to mitigate many of the aforementioned problems (and especially those of climatic nature). The following strategies should be considered in addition to the existing public policies.

- **Environmental Education, Communication and Art:** One of the most important actions, even more important than the actual planting seems to be environmental education because it decreases vandalism, increases acceptation, participation, survival rates of newly planted trees and the tacit understanding of the benefits and necessity of urban greening. Here *Urban Environmental Art* may be an interesting link between the population and its stakeholders.

- **Preserving and maintaining the remaining Vegetation Cover** especially in the peripheries avoiding further deforestation to maintain the original forest and its unrecoverable ecosystems. Further urban sprawl should be avoided mainly by changing municipal social housing policies, seeking for affordable qualified density with environmental quality and thus green space within the central region e.g. by recycling brownfields and other urban voids with green developments.
- **Financial incentives like lowering taxes for maintaining trees on sidewalks for green fascades or roofs** is more stimulating than requirements, bans and rules and could incorporate an economical valorization of trees in public policies. Soares (2007) mentions e.g. the application for *Imposto Predial e Terretorial Urbano* (IPTU) in the city of São Paulo.

- **Stimulating the Participation and Collaboration of the Citizens** (in combination with environmental education) through voluntary activities and especially the collaboration with NGO's is important. However it must not be forgotten that planting and maintenance of the urban forest is originally a matter of public realm which must be approached and supervised at a citywide planning scale by a public organ.

- **Maintaining a maximum of existing vegetation on-site** avoiding the common slash-and burn *tabula-rasa,* focus on e.g. tax incentives for maintenance rather than on compensation plantings (TCA). The Term of Environmental Compensation (*Termo de compensação ambiental* – TCA) is a useful instrument but it substitutes mature trees by young trees which take years to substitute the environmental benefits of the mature. Generally the *Green Plot Ratio GPR* (Ong, 2003), see chapter 4.2.3, can be an interesting indicator to find an equilibrium between constructed and natural urban environment, but it should be developed further.

- **Climate adaptation though shade:** The functional use of horizontal and vertical vegetation canopies as shading elements to increase energy efficiency of buildings as well as thermal comfort outdoors by protecting urban surfaces and users against solar radiation. In hot environments evaporating leaf surfaces are more efficient (cooler) than any other shading element. If the overhead shading element consists of evaporating (cool) leaves the shade will be cheaper and more efficient (on the long run), then if it was created by any conventional shading elements which reflect or absorb (heat up), need more maintenance etc.

- **The improvement of the natural urban ventilation:** By planning green corridors which allow ventilation, evaporation cooling, shade, bicycle and pedestrian paths etc. and fostering more organic built forms (because these decrease urban roughness and improve ventilation) different aims of more efficient use of public urban floor space.

- **Desealing of soils:** Rendering soils more permeable allows infiltration of absorption of stormwater avoiding inundations and allowing evapo(trans)piration (when linked to planting) decreasing surface temperatures and mitigating urban heat island(s), increasing thermal comfort. Permeable side-walks, parking-lots, gardens etc.

- **Prefer and invest in sustainable transport linked to green:** Looking at the existing (constructed) city and its massive transportation problems (including those linked to it) it must be pointed out, that a high density can only be a successful and sustainable concept when public transport is well developed. Ground-based bus-rapid transit corridors concentrated with expressways and/or situated along rivers tend to cut connections between quarters, so that cross-fluxes need to be well-developed (Green/ living bridges). As mentioned before only light vegetation should be planted along the corridors, in order to permit the dispersion of pollutants.

- **Built an integrated *Green Infrastructure Network*:** The development of an integrated citywide (literally) green transport network which seeks to strategically interconnect the existing fragments, parks etc. A shade infrastructure will foster alternative locomotion like walks by foot, jogging, cycling, skating etc. which is emission free and health supporting. Especially in hot urban environments shade trees are crucial design elements to accompany infrastructure for pedestrian and cycling paths, streets, central reserve, linear parks etc.

- **Re-implanting (or "interweaving") street tree cover into existing dry**

[6] Parts of these findings may also be transferable to other big cities in similar latitudes

urban fabrics: Most important in terms of urban climate is to cover large open asphalted areas (such as parking lots) and broad streets (avenues and expressways) with tree which have a horizontal spreading character that provides shade to the surroundings. For replanting within city, the urban climate map (see fig. 3.25) indicates the districts with the highest necessity to modify the *summer heat island climate* towards an *urban forest/ oasis climate* (principally the eastern districts).

- **Mind the Gap:** Literally any urban void no matter the size bears chances for urban interventions; any open space within the urban fabric (especially brownfields) can turn a green space, with associated environmental services and quality. Especially the degraded historical downtown of São Paulo possesses almost no vegetation and offers interesting options. Planting in São Paulo's often narrow street canyons is certainly a difficult task but could help to improve comfort and quality. Accessible by generating dignified, central and sustainable popular housing within the central region (e.g. on brownfields) is highly recommendable instead of in peripherical areas (like many CDHU projects).

- **The integration of natural elements with man-built elements to generate qualified density:** This strategy can attack especially the reduction of social contrasts in a diplomatic, non-aggressive way creating *fuzzy boundaries* between the public and the private. This form of delimiting property could be discussed in megacities as an important benchmarks.

- **Every little helps -** Everything counts even in small amounts which is true for damages and benefits, as they sum up and/or multiply. In other words: "Collectively we must come to the realization that there is no exterior to our ecology. There is only one environment and everything is entered on the balance sheet. Every positive. Every negative. Everything counts" (Mau and The Institute without Boundaries, 2004)

- **Verticalisation and Stacking of Vegetation** since floor space is limited and occupied while noteworthy greening potentials in many places are principally localized on the building surfaces. Especially the introduction of green roofs over the existing structure, covering city buildings in vegetation – creating "*green roofs and walls*" seems to be one of the few options to introduce more vegetation in megacities which do not have much room for lots of additional trees. Since according to Scott (2006) light-colored roofs only partially reduce urban heat and in no way reduce runoff, just one option remains: vegetation-covered roofs.

The "Urban Jungle" morphology and analogy

As mentioned before land-use and form (morphology and sky view factor) shape the (micro)climate of a place by modifying the radiation balance through ground shading. Analogies between cities and living beings like "urban metabolism" (Pauliet and Duhme, 2000) are common and the idea of an "Urban Jungle" or "Asphalt Jungle" is apparently globally understood today, making part of the global conscience. In Brazilian Portuguese e.g. the term "*Selva da Pedra*"[7] (Brick forest) is used for São Paulo and in German *"(Gross-) Stadtdschungel*" are widely understood.

An interesting question here is, in how far the city of São Paulo is similar to a real forest in morphological terms? In how far can (or must) the tropical city approximate morphologically to a tropical forest? Tay (1989, cited by Ong 2004) proposed as an ideal morphology for the tropical megacity to replicate the tropical forest, additionally cooled by plants, finding the balance between light (solar access) and shade; McDonough and Braungart (2002) make a very similar analogy: "A city like a forest, cool and quiet" (p.14) and "the city is a forest, the building a tree".
In the 2007 film *Bem Vindo a São Paulo* (Welcome to São Paulo) (Mostra Filmes/ Video Filmes 2007) Brazilian poet Caetano Veloso[8] (citing his poem *Concreto*[9]) reads out names of residential high-rise buildings in São Paulo baptized after tree species of the native *Atlantic forest* biome in Guarani-Tupi- language: "Jacaranda, Caiua, Paraparai, Urucum, Ibirapitanga, Orabuta, Ibirapita - Pau Brasil)"

Martin and Keefee (2007) propose a methodology to derive urban form from a forest-growth inspired methodology to improve solar access in Manchester (51º N) based on Ralph Knowles *Solar envelope* and "natural forest gap algorithms" in an "intensified light stratified system".

The climatic adaptation of a city tropical (or a place in a tropical city) highly depends on the local sky view (see fig. 6.5) and orientation since shade is the most important property for thermal comfort. Especially over-head shading devices, such as trees and solar sails are crucial for the generation thermal comfort in tropical latitudes due to zenithal altitudes of the sun at critical hours about noon when the buildings cast no shadows.

The forested natural landscapes of the São Paulo region were usually closed (had a low sky view factor) just as many regions in the city have today due to densification, verticalisation and deep street canyons. However open (desert) landscapes, horizon views, farsightedness and hugeness of the sky are important perceptions (if not myths) often associated with the *New World* (see e.g. Williams, 2005 on Brasília). As mentioned in São Paulo the higher the storey of an apartment in residential high-rise buildings the higher its value. Buildings seem, like trees, to compete for light while it is in fact the best views into the urban landscape.

However the most significant morphological difference between the urban structure of São Paulo and the original *Atlantic Forest* biome is that overhead shade (which leads to thermal comfort around midday) is rare.

[7] Literally "Brick forest", reference to a the Brazilian Telenovela 1972 & 1986
[8] Caetano Veloso (1947 -) is a reknown popular singer and songwriter of the tropicalismo movement
[9] Conceto = Concrete

Therefore at neighbourhood scale, for master-planning and concerning built form (morphologies) the following issues should be considered to generate high performance urban landscapes with maximum thermal comfort:

- **Consider Typography:** Prefer hilly regions or river valleys for plantations to maximize canopy rainfall retention and root erosion control of the increased stormwater runoff and speed caused by the typography.

- **Consider Building Height and Shade:** verticalized, highly dense fabrics with deep narrow canyons (low h/w ratios) and sky view restricted by buildings depend less on tree shade than low-rise regions with high sky view factors. Therefore (densely populated) low-rise regions should be preferred because tree-shade is more important due to large SVF and because trees can shade roofs of low rise buildings (e.g. east zone of São Paulo).

- **Consider Orientation of the Grid:** It was found in the microclimate studies (see chapter 7.1.1) that urban grids rotated out of the east-west axis are preferable because the urban geometry generate more self shading during the summer, especially when buildings are high. The most recommendable angle is 45º. In master-planning and in case of new land divisions orientate the grid 45º to the North-South & East-West orientation axis.

- **Bioclimatic Urban Typologies:** The development of naturally ventilated, permeable structures, which integrate natural and man-built elements, private and public space and use, incorporating climate-sensitive design like sky gardens, green roofs and fascades etc. seems important, but only possible if urban noise and air pollution from traffic in the future city was possible to be mitigated. This could result in *a new tropical building style* or *paradigms* which unites landscape and building incentivizes new forms of urban vegetation (especially urban farming[10] etc.) which are innovate solutions for urban environmental problems.

At micro scale it is important to consider canopy and root structure, which depends mainly on the genetic information of the species and the microclimatic situation. Here the following guidelines should be considered:

- **Avoid to plant species with aggressive roots** and very dense crowns (like Ficus) in order to permit daylight transmission and dispersion of pollutants through ventilation.

- **Prefer species with small leafs and deep roots** (e.g. Pau Ferro etc.). A medium shade generates most efficient comfort, allowing light transmission and the dispersion of pollutants due to the more laminar wind-flux.

- **Plant *See-through-Trees*** Mid-to-low density trees transmit enough sunlight (to maintain illumination levels and attenuate enough solar radiation to generate thermal comfort. They are less of an obstacle for the wind and generate 'cushions' not 'lee eddies' (Oke. p. 214)

- **Benefits generally tend to increase** with diameter-at-breast height (DBH), age, size and leaf area (and decreased transmission) but leaf area (density) should be limited due to decreased light transmission and dispersion of pollutants. Plant (and maintain) local, native (costal rainforest biome), low to mid-density, semi-deciduous species because they are climatically most adapted and resistant against heat and water stress (low stomata resistance) as well as against vermin.

- **In areas in which fast urban change happens** e.g. due to real estate speculation plant fast growing trees (Pioneer species) together with slower growing (secondary) species are recommended to improve the chances of the latter to survive.

7.5 Final Considerations

In the light of global heating the strategy of "*Shade everything, including buildings, especially the sidewalks*" created in the *Lessons from Brisbane*/ Australia (see chapter 2.4) seems particularly interesting strategy for cities located in hot climates to deal with climate change at reasonable costs: shade mitigates peak thermal discomfort, while air temperatures (and thus the urban heat island) are secondary for the generation of thermal comfort, as shown in chapter 7.1.1.

The concept of "*light shades everywhere*", could focus mainly on overhead shading elements like trees (especially because the bear other benefits) and should be put on the regional agenda of predominantly hot, subtropical megacity like São Paulo.

As mentioned the leaf density of urban forests is important for their performance, but it must be pointed out that this does (at street canyon scale and context) does not necessarily mean that the higher the leaf area the higher the benefits: Contrary the "light" shade should be cast not very dense trees because dense canopies decrease the wind velocity, the dispersion of pollutants and daylight access (and thus are drawbacks which generate indirect costs, see table 5.2.2).

Limitations

It was not possible, as initially planned, to estimate the environmental benefits of a mean urban, isolated tree (as many American studies try), because this would be a helpful measure for planners. This is due to the heterogeneous distribution of vegetation fragments, street trees etc. in São Paulo's large municipal area, the large number of parameters per individual which needed to be considered to simulate and calculate mean benefits and the method applied, which regards land-use and vegetation cover and is not based on large numbers of street tree inventories.

[10] see e.g. http://www.verticalfarm.com/Designs.aspx <access on 25th of June 2009>

As indicated in terms of increased energy efficiency of urban trees by McPherson and Simpson (1995) two trees are about five times more effective than one isolated tree which seems to be a general tendency: An inter-connected canopy cover brings more environmental benefits than isolated trees and is of great importance for urban ecosystems. The example of the benefit of two trees, which is more than twice of one tree illustrates the high dynamics of impacts of urban trees being part of urban ecosystem and microclimates which cannot yet be simulated in a satisfying way.

Although tools exist which simulate enrichment and balance of urban ecosystem as well as sound-barrier properties) simulations were not executed due to complexity.

Estimations of vegetated/ leaf mass of existing and future plants as a planning indicator for a more equilibrated relation (volume/ area) between constructed and natural environment (based on the Leaf Area Index) was proposed with the *Green Plot Ratio* by Ong, 2003. The indicator remains an interesting approach (even for legislation) although the orientation of the leaf mass relative to buildings (strategically, functional planting) is important especially in hot climates and not yet considered.

Benefits beyond Conceivability

There is a multitude of impacts from urban vegetation that must yet be classified *beyond conceivability,* because they are difficult or even impossible to quantify and/or to monetize. The magnitude and weight of these benefits highly depends on subjective perception, imagination, education and thus the value the individual attributes to these benefits.

The approach made in the chapter thermal comfort shows the application of one fuzzy indicator, which depends to a limited degree on individual perception (and adaptation). Research which seeks to assess even cultural tendencies through surveys, analyzing consensuses of the surveyed to develop indicators is as complex as recommended in order to access and introduce perceptional issues into planning and transformation processes.

As pointed out literature research indicated *immeasurable* and/ or *fuzzy* mainly social (or even spiritual) benefits of urban vegetation linked e.g. to concepts like *aesthetics and/or beauty, environmental justice and comfort* and *quality of life* beyond the environmental ones (estimated in the preceding chapters). The increasing importance of these concepts has been documented through literature research and cannot be neglected. Especially the aspect of *aesthetics* and/or *beauty* is (like e.g. also the issue of biodiversity, see 5.3.1) is on one hand a difficult parameter on the other it is too essential to be excluded from this discussion.

According to Jensen *et. al* (2004) and McPherson *et. al* (2005) the perceptions of the site location and greening degrees of the street, neighbourhood etc. are directly reflected in median housing and property values and have also impacts on psychological health and well being (see Grahn and Stigsdotter, 2003). It is unquestioned that sufficient and well planned green spaces linked to quality of life attract investments, which underlines the “aesthetic and other benefits” which is in McPherson *et. al* (2005) are rated the highest of all benefits and even above the environmental.

It appears as if in the discourse about urban vegetation in North American literature the concept of *aesthetics* is used synonymous as a translation of the valorization of real estate/ property (Petit *et. al.* 1995, McPherson *et. al.* 2005), while in Brazilian literature the more poetic concept of *beauty* is predominant (Robba and Macedo, 2003).

Green, Aesthetics, Beauty and Function

Although widely used the concepts of *aesthetics* and *beauty* are not well defined and understood differently by theorists and citizens without urbanistic background. Generally *aesthetics* can be understood as a scientific approach to *beauty.*

Since the dawn of the modern age (after the Garden City) functionality has become a more discussed issue than the picturesque, idyllic, ornamental and beautiful. The aesthetics of things were therefore judged as result of their function (functional design). The *Beauty of Nature* which had been inspiration of artists for centuries lost its importance.

Green space was perceived as wastage of urban space which could be capitalized. After almost a century of complete absence in the discourse (metropolitan blindness) the literally urban green is returning and increasingly recognized as a unique and functional urban element to improve social, environmental and economical balances especially in the light of climate change (“Design on the Grill”). Vegetation or Green has even been called *the New Granite* by McElroy and Walz (2007).

However it is recognized that the ‘monetisation’ of benefits bears a danger of ‘commoditisation’ so that the often mentioned “change of paradigm” could paradoxically lead to a new urban fetish – the tree. This tendency linked to properties in privileged districts (see 5.3.2) is clearly readable in the mentioned real estate enterprise launch flyers collected between 2007 and 2008.

Within the concept of so-called *Green Design/ Building/ Construction* the word GREEN (which can have “more than a half-dozen meanings”), has become a misleading buzzword, synonymous for sustainability and with a high symbolical content. When it comes to the use of its literal meaning, as greenery of nature (grass, trees and leaves), like in this work, it seems, that its aesthetics and functions need to be discussed among planners.

Fig. 7.9: Turn urban non-places (see fig. 2.7) into collective (green) spaces which invite for stop-bys and temporary stays and foster urban quality of life and sustainability

REFERENCES

Abreu, L. V. (2008) *Avaliação da Escala de Influência da Influência da Vegetação no Microclima por Diferentes Espécies Arbóreas* Master Thesis Universidade Estadual de Campinas – Faculdade de Engenharia Civil, Arquitetura e Urbanismo

Akbari, H.; Pomerantz, M.; Taha, H. (2001) *Cool Surfaces and shade trees to reduce energy use and improve air quality in urban areas* In: Solar Energy Vol, 70, No.3 pp. 295-310 2001

Akbari, H.; Huang, J.; Martien, P.; Rosenfeld, A.; Taha, H. (1988) *The Impact of Summer Heat Island on Cooling Energy Consumption and CO2 Emissions*. In: Berkeley UC, P5.11-5.23. (Publication LBL 25179)

Alexandri, E.; Jones, P. (2006) *Developing a one-dimensional heat and mass transfer algorithm for describing the effect of green roofs on the built environment: Comparison with experimental results* In: Building and Environment 42 (2007) 2835–2849

Alexandri E.,Jones, P. (2006) *Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates* In: Building and Environment 43 (2008) 480–493

Ali-Toudert, F; Mayer, H. (2003): *Street Design and Thermal Comfort in Hot and Dry Climate* In: Proc. Fifth Int. Conf. Urban Climate, 2003; Vol. 2: 207-210 (Fifth Int. Conf. Urban Climate, Lodz, Poland), Klysik K.; Oke T.R.; Fortuniak K.; Grimmond C.S.B.; Wibig J. (Editors)

Ali-Toudert, F; Mayer, H (2005) *Dependence of Outdoor Thermal Comfort on Street Design in Hot and Dry Climate* Phd Thesis Fakultät für Forst- und Umweltwissenschaften der Albert-Ludwigs-Universität Freiburg

Ali-Toudert, F.; Mayer, H. (2005). *Thermal comfort in urban streets with trees under hot summer conditions*. In: D.K. Raydan and H.K. Melki (eds.), Proc. of 22nd PLEA Conf., Beirut, Lebanon, 2005, pp. 699-704

Ali-Toudert, F, Mayer H (xxx) *Effects of Street Design on Outdoor Thermal Comfort* Online: http://www.sci.u-szeged.hu/eghajlattan/baba/Ali-Toudert.pdf
Ali-Toudert, F.; Mayer, H. (2007). *Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons* In: Solar Energy, vol. 81, pp. 742-54

Almarecegui, L. (2006) Guide of the Wastelands of São Paulo (27th Bienal of São Paulo 2006 “Como Viver junto” Curated by Lagnado, Martinez, Pedrosa, Freire, Volz, Roca)

Almarecegui, L (2006b) The Construction Materials of São Paulo (27th Bienal of São Paulo 2006 “Como Viver junto” Curated by Lagnado, Martinez, Pedrosa, Freire, Volz, Roca)

Alucci, M. P. (2005) *Tensil 1.2 - Coberturas têxteis: determinação das características térmicas e luminosas* In: http://www.usp.br/fau/ensino/arq_urbanismo/disciplinas/paginas/conforto.html downloadable at http://www.usp.br/fau/pesquisa/laboratorios/labaut/conforto/index.html <access on 27th of June 2009>

Alucci, M. P. (2006) *Manual para dimensionamento de aberturas e otimização da iluminação na arquitetura* In: FAUUSP 2006 84p.il

American Forests (2002) *CITYgreen 5.0 for ArcView User Manual - Calculating the Value of Nature* American Forests, Washington D.C.

American Forests (2004) *CITYgreen 9.2 for ArcGIS User Manual - Calculating the Value of Nature* American Forests, Washington D.C

Anderson, L.M.; Cordell, H. K. (1988) *Residential property value improve by landscaping with trees*. In: South. Journal for Applied Forestry 9:162-166

Andreas, P. (2003) *Niemeyer und die Landschaft* In: Oscar Niemeyer: Eine Legende der Moderne, Birkhäuser 2003 ISBN 3764369922)

Arnfield J. A., Grimmond C.S.B. (1998): *An urban canyon energy budget model and its application to urban storage heat flux modelling* In: Energy and Buildings

ASHRAE - American Society of Heating, Refrigeration and Air-Conditioning Engineers (2004) *Thermal Environmental Conditions for Human Occupancy* In: ANSI/ ASHRAE Standards Committee 55-2004

Assis, E. S., Frota, A. B., (1999): *Urban bioclimatic design strategies for a tropical city* - comparison of scale model and field observations In: Atmospheric Environment, Volume 33, Number 24, October 1999 , pp. 4135-4142(8)

Assis, E. S. (2005) *A Abordagem do Clima urbano e Aplicações no planejamento da cidade: Reflexões sobre uma Trajetória* In: ENCAC – ELACAC 2005, Maceió

Augé, M. (1994) *Orte und Nicht-Orte. Vorüberlegungen zu einer Ethnologie der Einsamkeit* In: dt. Frankfurt: Fischer 1994

Azevedo, T. R. (2001b). *O fluxo de calor gerado pelas atividades humanas no estudo climático da Região Metropolitana de São Paulo* In: Tarifa, J. R. & Azevedo, T. R. de (orgs) Os climas da cidade de São Paulo: teoria e prática, Editora Contexto, São Paulo.

Bartelt, D. D. (2008) *The Hinterland is Elswhere*, In: Arch+ 190 Stadtkultur in São Paulo-Ausblick auf ein soziales Raumkonzept 123

Bartholomei, C.L.B (1998) *Estudo da Atenuação da radiação solar incidente por diferentes Espécies arbóreas* (Master thesis Unicampi)

Bartholomei, C. L. B. (2003) *Influência da Vegetação no Conforto térmico e no Ambiente Construído* In: Der Einfluß der Vegetation auf das thermische Wohlbefinden in der gebauten Umwelt (Universidade Estadual de Campinas, Faculdade de Engenharia Civil)

Barz-Malfatti ; Hildegard ; Guerra, M. W. (2005) *Straßen, Wege, Plätze*. In : Die Erneuerung des öffentlichen Raumes. (Städtebauförderung 1991-2003. Herausgegeben vom Thüringer Innenministerium.)

Bassuk, N., Trowbridge, P. (2004) *Trees in the Urban Landscape* In: John Wiley & Sons Inc

Behling; Sophia; Stefan (1996): *Sol Power - The Evolution of Solar Architecture* In: Prestel Verlag (Munich, New York) (Including an introduction by Sir Norman Foster)

Bernatzky, A. (1982) *The Contribution of trees and Green space to a town climate* In: Energy and Buildings, v 5, p. 1-10

Bistafa, S. (2006) *Acústica Aplicada ao Controle do Ruído* Editora Edgard Blücher São Paulo (p. 206)

Blazejczyk, K.; Tokura, H.; Bortkiewcz, A.; Szymczak, W. (1999) *Solar radiation and thermal physiology in man* In: International Congress of Biometerology & International Conference on Urban Climatology, 15, 1999, Sydney

Blazejczyk, K. (2002) Assessment of recreational potentional of bioclimate In: International Workshop on Climate, Tourism and Recreation, 1, 2001, Greece. ISB, p. 133-52

Blazejczyk, K. (2004) Man-environment heat exchange model Accessed in 24/04/2004. Online: http://www.igipz.pan.pl/klimat/blaz/menex.ppt.

Blouin, G.; Comeau, R. (1993). *First Canadian urban forests conference* In: Canadian Forestry Association, Ottawa, Ontario, Canada.

Bodemann, B. (2002) *Mega-Cities* In: Exposé Nachdiplomstudium in Raumplanung, Institut für Orts-, Regional- und Landesplanung ETH Zürich

Brandt (2007) *Estimating the economical effects of the urban climate* In: PhD thesis Bochum/ Germany

Breda, N. J. J. (2003) *Ground-based measurements of leaf area index: a review of methods, instruments and current controversies* In: Journal of Experimental Botany, Vol. 54, No. 392, pp. 2403±2417, November

Brown, N.; Jennings, S.; Wheeler, P.,Nabe-Nielsen, J. (2000) *An improved method for the rapid assessment of forest understorey light environments* In: Journal of

Brown, R. D.; Gillespie, T. J. (1995) *Microclimatic landscape design: Creating thermal comfort and energy efficiency* In: John Wiley & Sons Inc. New York, NY. 193p. Applied Ecology 2000, 37, 1044-1053

Bruse, M., Fleer H. (1998): *Simulating Surface-Plant-Air Interactions Inside Urban Environments with a Three Dimensional Numerical Model* In: Environmental Software and Modeling, 13: 373-384)

Bruse, M.; Thönnessen M.; Radtke U. (1999): *Practical and theoretical investigation of* *the influence of facade greening on the distribution of heavy metals in urban streets*. In: Biometeorology and Urban Climatology at the Turn of the Millennium, WMO/TD No. 1026, World Meteorological Organisation, Geneva, CH, ISBN 92-63-01026-9, 6 pages)

Bruse, M. (2007) *Multi-Agent Systems - A new approach for assessing urban environmental conditions* In: Post-doctoral habilitation thesis at the Faculty of Geosciences, Ruhr-University Bochum, Germany Online: www.botworld.info

Bruse, M. (2007) *Particle filtering capacity of urban vegetation - A microscale numerical approach*

Bruse, M. (2008). *ENVI-met v. 3.1 experimental* In: http://www.envi-met.com

Buckminster-Fuller, R. (1969): *Operating Manual for the Spaceship Earth*, In: Bedienungsanleitung für das Raumschiff Erde, translation by Joachim Krauss, Overseas Publishers Asssociation, Amstedam B.V.

Buarque de Hollanda, S. (1936) *Raízes do Brasil*. Rio de Janeiro: J. Olympio, 1936. 3rd edition 1990

Bueno, C. L. (1998) *How much does the change of species of trees affect their solar radiation attenuation?* In: Carolina Lotufo Bueno-Bartholomei*, Lucila Chebel Labaki State University of Campinas, Campinas, SP, Brazil

Bueno, C.L.B.; Labaki, L.C.; Vianna, P.Z. (2001) *Comportamento de diferentes espécies arbóreas quanto a atenuação da radiação solar* In: VI Encontro Nacional e III Encontro Latino-Americano sobre Conforto no Ambiente Construído, São Pedro, SP, Brasil

Ca V.T.; Aseada T.; Ashie Y. (1998) *Utilization of porous pavement for the improvementof summer urban climate* In: Proc. 2nd Japanese-German Meeting "Klimaanalyse für die Stadtplanung". Research Centre for Urban Safety and Security. KobeUniversity, Sp. Rep. No. 1: 169-177.

Caballero Deloya, M.C. (1993) *Urban forestry in Mexico City* In: An international journal of the forestry and food industries - Vol. 44 – Online: http://www.fao.org/docrep/u9300e/u9300e06.htm <access on 27th of June 2009>

Caldeira, T. P. R. (1992) *City of Walls : Crime, Segregation, and Citizenship in São Paulo* In: Dissertation for the degree of Doctor of Philosophy in Anthropology in the Graduate Division of the University of California at Berkeley, p. 257.

Chatzidimitriou, A.; Chrissomallidou, N.; Yannas, S. (2005). *Microclimate modifications of an urban street in northern Greece.* In: D.K. Raydan and H.K. Melki (eds.), Proc. of 22nd PLEA Conf., Beirut, Lebanon, pp. 689-94

Chenga. S; McBride, J.R. (2006) *Restoration of the urban forests of Tokyo and Hiroshima following World War II* In: Urban Forestry & Urban Greening 5 155–168

Cintra, M (2008) *Os custos do congestionamento na capital paulista* In: Conjuntura Econômica, June

Cristina, S.J.; Braga, J. (2005*) Urban Green Spaces and Environmental Quality* In: Spatial Analysis of Águas de São Pedro, São Paulo State Caminhos de Geografia 18 (16) 207- 224, out Página 211 http://www.ig.ufu.br/revista/volume16/artigo19_vol16.pdf <access on 27th of June 2009>

Corbella, O.; Yannas, S. (2003) Em *Busca De Uma Arquitetura Sustentavel Para Os Tropicos* In: Conforto Ambiental published by Editorial Revan

Corrêa da Costa, G.J. (2005) *Iluminação Econômica* In: EDIPUCRS third edition

Costanza, R. et. al. (2008) *An Integrative Approach to Quality of Life Measurement* In: Research, and Policy S.A.P.I.EN.S. 1 (1)

Cristina, S.J.; Braga, J. (2005) *Urban Green Spaces and Environmental quality: Spatial Analysis of Águas de São Pedro* In: São Paulo State Caminhos de Geografia 18 (16) 207-224, out/2005 Página 211

De Oliveira, O. (2006) *Jardim tropical: Crítica a uma específica arquitetura formalista e funcionalista* In: (Tropischer Garten: Kritik an einer bestimmten formalistisch/funktionalen Architektur) In: Lina Bo Bardi: Sutais Sustâncias da Arquitetura (Subtile Substanzen der Architektur) RG + GG

DeGraaf, R.M. (1985) *Residential forest structure in urban and surbuban environments: Some Wildlife Implications* In: New England Journal of Arboriculture. 11(8): 236-241.

Detzel, V.A. (1993) *Desenvolvimento de um método de avaliação monetária de árvores urbanas e aplicação a situação de Maringá* In: UFPR

Doxiadis, K. A. (1974) *Ecumenopolis: the Inevitable City of the Future* (with J.C. Papaioannou) In: Athens, Athens Publishing Center, 1974; New W.W. Norton, 1976 Building Entopia (Athens, Athens Publishing)

Duarte, D.; Souza, T. (2005) *Urban Occupation Patterns and Microclimates in São Paulo – Brazil*. In: SB 2005. Sustainable Buildings, Tokyo, Japan.

Dwyer, J. F. (1993) *The Economic Contribution of Trees to Urban Communities* In: Trends - Justifying Recreation and Parks to Decision Makers, v. 30, no. 4.

Eliasson I., Upmanis H. (2000): *Nocturnal airflow from urban parks-implications for city ventilation* In: Theor. Appl. Climatol. 66: 95-107

Embasz, E. (1995) *Die grünen Städte: Umweltschutz und Architektur* In: Architektur der Zukunft Finest S.A. Editions Pierre Terrail, Paris

Emmanuel, M. R. (2005). *An Urban Approach to Climate-Sensitive Design – Strategies for the Tropics,* In Spon Press, New York ISBN 0-415-33409-8

EMPLASA (2006) *Uso do Solo* - Arquivo do Mapeamento contínuo da Base Cartográfica e temática relativa à área total do Mapeamento

Escobedo, F. J., Nowak, D. J., Wagner, J. E., Luz De la M., Rodriguez, M. Crane, D.E., Hernandez, J. (2006) *The socioeconomics and management of Santiago de Chile's public urban forests* In: Urban Forestry & Urban Greening 4 (2006) 105–114

Fanger P. O. (1970) *Thermal comfort* In: Danish Technical Press. Copenhagen

FAO – Comitê de Agricultura (1999) *La agricultura urbana e periurbana* Roma Online: http://www.fao.org/unfao/bodies/coag/coag15/x0076s.htm <access on 27th of June 2009>

Fauzi, R. (1991) *The Hanging Gardens are the refrigerator of Babylon*. In: Masao Mori/ Hideo Ogawa/Mamoru Yoshikawa (Hrsg.), Near Eastern Studies dedicated to H. I. H. Prince Takahito Mikasa on the occasion of his Seventy-Fifth birthday (Wiesbaden 1991), 349-361

Feldman, S. (2005) *Planejamento e zoneamento. São Paulo 1947-1972*

Felix, R. Bowers, R.V. (2005) *Mental Hygiene and Socio-Environmental Factors* In: The Milbank Quarterly, Vol. 83, No. 4, 2005 (pp. 625–46)

Ferreira, S.; Wolff, S. (2001) *Jardim America – O primeiro Bairro-Jardim de São Paulo e sua Arquitetura* Edusp

Frazer, G. W.; Fournier, R. A.; Trofymowc, J.A.; Hall, R. J. (2001) *Comparison of Digital and Film Fisheye Photography for Analysis of Forest Canopy Structure and Gap Light Transmission* In: Agricultural and Forest Meteorology 109 249–263

Freitas, E. D. (2003) *Circulações locais em São Paulo e sua influência sobre a dispersão de poluentes* São Paulo, 2003, 156p. Tese de Doutoramento do Departamento de Ciências Atmosféricas do Instituto de Astronomia, Geofísica e Ciências Atmosféricas da Universidade de São Paulo

Freitas, E. D.; Rozoff, C. M.; Cotton W. R.; Silva D. P. L. (2007). *Interactions of an urban heat island and sea-breeze circulations during winter over the metropolitan area of São Paulo, Brazil* In: Boundary-Layer Meteorology, vol. 122, pp. 43–65

Fundação Bienal de São Paulo (1997) *Cidades Jardins – A busca do equilíbrio social e ambiental* 1898-1998 3ª Bienal Internacional de Arquitetura

Geiger, R.; Aron, R.; Todhunter, P. (1995): *The climate near the ground* In: Vieweg. Wiesbaden.

Goldemberg, J. (1995) *Energia Desenvolvimento e Meio Ambiente*. São Paulo: EDUSP/ CESP

Gouvêa, L. A. C (2002) *Biocidade - Conceitos e cirtérios para um desenho ambiental urbano, em localidades de clima tropical de planalto* In: AMPUB/ PROL/ Nobel, São Paulo

Gouvêas, M. L. (2007) *Cenários de impacto das propriedades da superfície sobre o conforto térmico humano na cidade de São Paulo* Máster-thesis University of São Paulo

Grahn, P., Stigsdotter U.A. (2003) *Landscape planning and stress* In: Urban For. Urban Green. 2 (2003): 001–018

Green, E. P., Clark, C. D. (2000) *Assessing mangrove leaf area index and canopy closure* In: lasdair, J. Edwards (Ed.), Remote Sensing Handbook for Tropical Coastal Management, Coastal Management Sourcebooks 3. Part 5. Quantitative Measurement of Ecological

Parameters and Marine Resource Assessment, CSI, UNESCO —http://www.unesco.org/csi/pub/source/rs13.htm <access on 27th of June 2009>

Grey, G.W.; Deneke, F.J. (1978) *Urban Forestry* In: John Wiley, New York, p. 279

Grimme, F.-W., Laar, M., Moore C. (2003) *Ventilation dependent comfort under tropical conditions* In: AiF-Report; Arbeitsgemeinschaft Industrieller Forschungsvereinigungen Otto von Guericke e. V.

Hardin, P. J., Jensen, R.R. (2007) *The effect of urban leaf area on summertime urban surface kinetic temperatures* In: A Terre Haute case study Urban Forestry & Urban Greening 6 (2007) 63–72

Hehl, R. (2008) *Traurige Entropie – Eine kurze Kulturgeschichte der Öffentlichkeit* In: São Paulo In: Arch+ 190 Stadtarchitektur São Paulo – Ausblick auf ein soziales Raumkonzept

Honjo T.; Takakura T. (1990/91) *Simulation of thermal effects of urban green areas on their surrounding areas* In: Energy and Buildings 15-16: 457-463.

Höppe, P. (1999) *The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment* In: International Journal of Biometeorology , vol. 43, pp. 71-75

Houghton, R. A. D.; Skole, C.; Nobre (2000) *Annual fluxes of carbon from deforestation and regrowth of the Brazilian Amazon* In: Nature, 403:301-304

Huang, J.; Ritschard, R.; Sampson, N.; Taha, H. (1992) *The benefits of urban trees.* In Akbari, H.S. Davi, S. Dorsano J. Huang and S. Winner (eds.) Cooling Our Communities, Policy, Planning and Evolution (PM-221). 22P-2001. PP 27-42. US Environmental Proction Agency. Washington. D.C. 217p

IBGE - Instituto Brasileiro de Geografia e Estatística (2000). *Censos Demográficos* In: A Tropical Microclimatic Environment (PLEA 2007)

Ip,K., Hoi-Yan Lam,M., Miller A. (2007) *Assessing the shading performance of climbing plant canopies* In: PLEA 2007

ISA - Instituto Socioambiental (2008) *Almanaque Brasil Socioambiental – Uma nova perspectiva para entender a situação do Brasil e a nossa contribuição para a crise planetária* In: Edited by Beto Ricardo e Maura Campanili ISBN 978-85-85994-45-7

Jacobi, P. (2006) *Cidade e Meio Ambiente – Percepções e práticas* In: São Paulo 2nd Edition Annablum Editora

Jacobs, J. (1961) *The Death and Life of great American Cities* In: Random House, New York, 1961

Jendritzky et al (1990) Unpublished

Jennings, S. B.; Brown, N. D.; Sheil, S. (1999) *Assessing forest canopies and understory illimination: canopy closure, canopy cover and other* In: Forestry, Vol 72, No. 1, (1999)

Jensen, R., Gatrell, J., Boulton, J., Harper, B. (2004) *Using Remote Sensing and Geographic Information Systems to Study Urban Quality of Life and Urban Forest Amenities* In: Ecology and Society 9(5): 5. Online URL: http://www.ecologyandsociety.org/vol9/iss5/art5/ <access on 27th of June 2009>

Jo, H.-K. and McPherson, E. G.(2001) *Indirect carbon reduction by residential vegetation and planting strategies in Chicago, USA* In: Journal of Environmental Management (2001) 61, 165–177 doi:10.1006/jema.2000.0393, available online at http://www.idealibrary.com

Johansson, E. (2006). *Urban design and outdoor thermal comfort in warm climates – studies in Fez and Colombo* In: PhD thesis, Housing Development & Management, Lund University, Sweden.

Jonckheere, I.; Stefan, S.; Fleck; Nackaerts, K.; Muysa, B.; Coppin, P.; Weiss, W.; Baret, F. (2004) *Review of methods for in situ leaf area index determination Part I. Theories, sensors and hemispherical photography*, In: Agricultural and Forest Meteorology 121 19–35

Jones, H.G. (1992) *Plants and Microclimate – A quantitative Approach to environmental plant Physiology* Second Edition, Cambridge University Press, Cambridge, UK

Joyce, C.; Lamberts, R. (2001) *Urban Climate and its influence on energy consumption - A case study in two Brazilian Cities* In: Seventh International IBPSA Conference Rio de Janeiro, Brazil August 13-15
Jung, C.G., Franz, M.L., Henderson, J.L. (1999) *Heilung und Spaltung* In: Der Mensch und

seine Symbole, Walter-Verlag

Jurrack, U.; Richter, A.; Schauber U. (2002) *Ökologische Gesamtkonzepte - Hilfestellungen zum Ablauf, zur Gliederung und zur inhaltlichen Bearbeitung von Beleg - und Projektarbeiten* (Vorlesungsskript Professur Ökologisches Bauen, Bauhaus-Universität Weimar)

Jusuf, S. K.; Hien, W. K.; La Win, A. A.; Thu, H. K.; Negara, T. S.; Xuchao, W. (2006). *Study on effect of greenery in campus area*, In: R. Compagnon, P. Haefeli and W. Weber (eds.), Proc. of 23rd PLEA Conf., Geneva, Switzerland, 2006, vol. I, pp. 483-88

Kageyama, P.Y., Gandara, F. G. (2000) *Recuperação de Áreas Ciliares* In: Rodrigues, R. R. & Leitão Filho, H. F.; Matas Ciliares: Conservação e recuperação São Paulo: EDUSP, 2000. 289 – 312p

Karlik, J. F., Winer, A. M. (2001) *Plant species composition, calculated leaf masses and estimated biogenic emissions of urban landscape types from a field survey in Phoenix* In: Arizona Landsc. Urban Plann. 53, 123–134

Katzschner, L. Maas, A. Schneider, A. (2007) *Das Städtische Mikroklima: Analyse für die Stadt- und Gebäudeplanung*

Klaus, L. S.; E. G. McPherson; J. R. Simpson (1998) *Air Pollution uptake by Sacramento's urban forest* In: Journal of Arboriculture 24(4): 224-233

Kleist, C.; Kockelhorn, A.; Kuhnert, N.; Ngo, A.L. (2008) *City Architecture or City of Walls* In: Arch+ 190 Stadtarchitektur São Paulo – Ausblick auf ein soziales Raumkonzept

Koch, M.; Seitz, W. et.al. (1998*): Verbesserung des Stadtklimas durch Grün - Wirkungen, Planung und Umsetzung-Seminarpapier im Rahmen der Veranstaltung*

Köckler, H. (2007) *Co-operative Indicators Development as an Instrument for Joint Implementation of sustainable Development* In: Revista Brasileira de Ciências Ambientais December 2007 No. 11

Köhler, M.; Schmidt, M. (1997) *Hof-, Fassaden- und Dachbegrünung – Zentraler Baustein der Stadtökologie – Zwölfjährige Erfahrung mit einer Begrünungsutopie* In: TU Berlin 1997, Landschaftsentwicklung und Umweltforschung, Schriftenreihe im Bereich Umwelt und Gesellschaft Nr. 105
Kohlhepp, G. (1997) *Ersticken die Megalopolen an sich selbst?* In: Der Bürger im Staat Heft: 2/1997 Großstädte

Konijnendijk, C. C. (2000) *Adapting forestry to urban demands - role of communication in urban forestry in Europe* In: Landscape and Urban Planning 52 (2000) 89-100

Konijnendijk, C. C. (2003) *A decade of urban forestry in Europe* In: Forest Policy and conomics 5 (2003) 173–186

Konijnendijk, C. C.; Ricard R. M.; Kenney, A.; Randrupd, T. B. (2006) *Defining urban forestry – A comparative perspective of North America and Europe* In: Urban Forestry & Urban Greening 4 (2006) 93–103

Koolhaas, R. (1999) *Stadtkultur an der Jahrtausendwende* In: Deutsche Verlags-Anstalt (DVA) Stuttgart/ Red. Stefan Bollmann Kursbuch Stadt - Stadtleben und Stadtkultur and der Jahrtausendwende)

Koolhaas, R. *et. al.* (2001) *Nature ≠ Natural* In: Harvard Project on the City: Mutations (Actar Editors)

Kravcík, M.; Pokorný, J.; Kohutiar, J.; Kovác, M.; Tóth, E (2007) *Water for the Recovery of the Climate - A New Water Paradigm* In: www.waterparadigm.org <access on 27th of June 2009>

Krusche, A.; Gabriel, I.; Krusche, M.W. (1982): *Ökologisches Bauen* (Ecological construction) In: Bauverlag Berlin, Wiesbaden

Kumar, S. (2002) *Does ''Participation'' in Common Pool Resource Management Help the Poor?* In: A Social Cost–Benefit Analysis of Joint Forest Management

Kuo, F.E.; Sullivan, W.C.; Coley, R.L.; Brunson, L. (1998) *Fertile ground for community: Inner-city neighborhood common spaces* In: American Journal of Community Psychology, 26(1), 823-85

Kuttler, W. (2004) *Stadtklima Teil 1: Grundzüge und Ursachen* In: Universität Duisburg-Essen, Campus Essen, Institut für Geographie, Abt. Angewandte Klimatologie und Land schaftsökologie,Universitätsstraße 5, D-45141 Essen

LABAUT - Laboratório de Conforto Ambiental e Eficiência Energética (2006). *Sustainable Urban Spaces*. In: Intermediate report: context studies and the strategy for environmental/ sustainable urban design. Colaboração Internacional Brasil-UK. Laboratory of Comfort and Energy Studies – LABAUT, FAUUSP. São Paulo, 2006. (To be published)

Lacerda, J. B. (1985) O Homem dos sambaquis In: Arq. Museu Nacional., 6:175-203, 1885.

Lalic, B., Mihailovic, D. T. (2004) An empirical relation describing leaf-area density inside the forest for environmental modeling In: J. Appl. Met. 43(4) 641-645

Lamberts, R.; Dutra, L.; Pereira, F. (1997): Eficiência Energética na Arquitetura In: PW Editores, São Paulo

Lang, S., Schöpfer E. (2005) Ein standortgewichteter Durchgrünungsgrad zur Bewertung der Wohnqualität in Salzburg (Mag. Stefan Lang und Mag. Elisabeth Schöpfer, Z_GIS – Zentrum für Geoinformatik, Universität Salzburg)

Laverne, R.J., Lewis, G. (1995) The Effect of Vegetation on Residential Energy Use In: Kollin, C. and Barratt, M. (eds.), Proceedings of the 7th National Urban Forest Conference, New York, Sept. 12-16, pp. 80-84

Lawson, M., O'Callaghan, D. (1995) A critical analysis of the role of trees in damage to low rise buildings In: Journal of Arboriculture 21 (2): March 1995 http://joa.isa-arbor.com/request.asp?JournalID=1&ArticleID=2668&Type=2 <access on 27th of June 2009>

Le Corbusier (1930) Precisões sobre um estado presente da arquitetura e do urbanismo (tradução Carlos Eugênio Marcondes de Moura; posfácio Carlos A Ferreira Martins) Cosac & Naify São Paulo 2004 (Edição Original 1930)

Le Corbusier (1930) Brasilianischer Zusatz (der auch für Uruguay Gültigkeit hat) In: Feststellungen p. 220

Leitao, A. B., Ahern, J., (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning In: Landsc Urban Plann. 59, 65–93.

Leite, C. (2002) Fraturas urbana e a possibilidade de construção de novas territorialidades metropolitanas: A orla ferroviária paulistana In : PhD thesis Faculdade de Arquitetura e Urbanismo da Universidade de São Paulo)

Levi-Strauss, C. (1952) *Traurige Tropen* (dt.1978, Ü. Eva Moldenhauer, Surkamp Taschenbuch Wissenschaft)

Lippsmeyer, G. (1980) *Building in the Tropics* In: 2nd edition Callwey Verlag, Munich

Lombardo, M. A. (1990) *Vegetação e Clima* In: Encontro Nacional sobre Arborização urbana, 3. Aneis, Curitiba, p. 1-13

Lombardo, M. A. (1985) *Ilha de Calor – O exemplo de São Paulo* (Editora Hucitec com apoio de Lelekla S.A.Comércio e Indústria

Long-Sheng, Mao, Yong Gao, Wen-Quan Sun (1993) *Influences of street treee systems on summer micro-climate and noise attenuation in Nanjing City, China.* In: Arboricultural Journal *17(3): 239-251.*

Lorenzi, H. (2002): *Árvores Brasileiras – Manual de Identificação e Cultivo de Plantas Arbórea do Brasil* In: Vol. 1 e 2 (Instituto Plantarum, Nova Odessa (www.plantarum.com.br) <access on 27th of June 2009> SBN 85-86714-06-2 e ISBN 85-86714-14-3

Lovelock, J. (2006) *The Revenge of Gaia* (Penguin Celebrations)

Souza, L.C., Yamaguti, M.L. (2007) *Orientation, Building Height and Sky View Factor as Energy Efficiency Design Parameters* (PLEA 2007)

Lyra R., Fernandes E.F. (2000) *Análise do clima urbano de Maceió-AL* In: Comparaçoes entre diversas escalas Giana Melo Barbirato

Maass, J.M., Vose, J.M., Swank, W.T. Martinez-Yrizarc, A. (1994) *Seasonal changes of leaf area index (LAI) In a tropical deciduous forest in west Mexico* In Forest Ecology and Management 74 (1995) 171-180

Maathai, W.M. (2006) *Inabalável* Editora Nova Fronteira S.A (original title Unbowed) Maathai The Green Belt Movement (GBM)

MacDonald, L. (1996) *Global problems, local solutions: measuring the value of the urban forest* In: American Forests 103 (4), 1996, p. 26.

Marcondes, S. (2006) *Brasil, amor à primeira vista - Viagem ambiental do século XVI ao XXI* In: Editora Peirópolis 345 páginas

Martin, C.L.; Keeffe, G. (2007) *The Biomimetic Solar City* In: Solar Derived Urban Form using a Forest-growth Inspired Methodology. (PLEA)

Martínez Alier, J (2007) *O Ecologismo dos Pobres*. Editora Contexto São Paulo

Martins, S. (2004) *Determinação do potencial de sequestro de carbono na recuperação de matas ciliares na região de São Carlos - SP* Doctorate Thesis Universidade Federal de São Carlos, Centro de Ciências Biológicas e da Saúde Programa de Pós-Graduação em Ecologia e Recursos Naturais

Mascaró, L. (1996*) Ambiência Urbana* In: 2nd edition Porto Alegre: Sagra: DC Luzzato, 199 p. 1996.

Mascaró, L. (2005) *Vegetação Urbana* In: 2. Auflage, Mais Quatro Editora, Porto Alegre

Matzarakis, A., Mayer, H., Iziomon, M. (1999) *Applications of a universal thermal index: physiological equivalent temperature* In: International Journal of Biometeorology 43. pp. 76-84

Matzarakis, A., (2001) *Estimation and Calculation of the Mean Radiant Temperature within Urban Structures* In: Available at http://www.mif.uni-freiburg.de <access on 27th of June 2009>

Matzarakis, A., Mayer, H., Rutz, F. (2002) *Radiation and Thermal Comfort* In: Meteorological Institute, University of Freiburg, Germany 6th Hellenic Conference in Meteorology, Climatology and Atmospheric Physics S. 739

Mau, B.; The Institute without Boundaries (2004) *Massive Change* (Paidon Press)

Mautner, V. A. (2003) Memória Ofativa: Aromas e cheiros de São Paulo In. São Paulo 450 anos http://www.dbkv.de/publikation/informativo_2_2004.pdf <access on 27th of June 2009>

Mayer H., Höppe, P. (1987) *Thermal comfort of man in different urban environments* Theor. Appl. Climatol. 38: 43-49

McDonough, W., Braungart, M. (2002) *Cradle to Cradle – Remaking the Way we make things* In: North Point Press, New York

McElroy, J, Walz, K. (2007) *Green Is the New Granite* In: Planning Chicago Jul. 2007 Vol. 73, Iss. 7 pg. 20 http://www.masterplannedcommunityjobs.com/Articles/green_is_the_new_granite.htm <access on 27th of June 2009>

McHale, M.R., McPherson, G. E., Burke, I. C. (2007) *The potential of urban tree plantings to be cost effective in carbon credit markets* In: Urban Forestry & Urban Greening 6 (2007) 49–60

McPherson, E. G. (1996) *Modeling Benefits and Costs of Community Tree-Planting in 12 U.S. Cities" and "Chicago's Urban Forest Ecosystem* In: Results of the Chicago Urban Forest Climate Project

McPherson, E.G. (1992) *Shading urban heat islands in U.S. desert cities* In: Wetter und Leben 44: 107-123.

McPherson, E. G. (1994) *Using urban forests for energy efficiency and carbon storage*. In: Journal of Forestry 92 (10) 36-41

McPherson E. G., Nowak D. J., Rowntree R. A. (1994b) *Chicago's urban forest ecosystem* In: Results of the Chicago urban forest climate project. USDA forest service. General Technical report NE-186.

McPherson, E. G., Simpson, J. R. Simpson (1995) *Shade trees as a demand-side resource* In: Home Energy, March/April 11-17 p

McPherson, E. G. (1998) *Structure and sustainability of Sacramentos's urban forest* In: Journal of Arboriculture 24(4): 174-189.

McPherson E. G., Nowak, D., Heisler, G., Grimmond, S., Souch C., Grant, Rowntree, R. (1999) *Quantifying urban forest structure, function, and value*: In The Chicago Urban Forest Climate Project Journal of Arboriculture 25(5): September 1999 http://www.urbanforestrysouth.org/cannedSearch?id=HotTopic.2004-06-24.5628

McPherson, E. G., Simpson, J. R. (2001) *Benefits and costs of LADWP's in Davis, CA* In: USDA Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research

McPherson, E. G., Simpson, J. R., Peper, P.J., Xiao, Q., Pettinger D. R., Hodel, D. R. (2001) *Tree Guidelines for Inland Empire Communities* In: Local Government Commission, Sacramento, CA. pp. 115.

McPherson, E. G., Simpson, J. R., Peper, J. P. (2005) *Municipal Forest Benefits and Costs in Five US Cities* In: Journal of Forestry

Meadows, D. L. et al. (2004) *Limits to Growth: The 30-Year Update* In: Chelsea Green Publishing Company 2004, ISBN 1-931498-58-X.

Medela, J. R. M. M. et. al. (2007) *Memória da Refrigeração e do ar condicionado no Brasil, Uma História a ser contada* In Sindratar São Paulo http://www.refrigeracao.net/Topicos/historia_refri_3.htm <access on 27th of June 2009>

Meir P., Grace, J. Miranda, A. C. (2000) *Photographic method to measure the vertical distribution of leaf area density in forests* In: Agricultural and Forest Meteorology Volume 102, Issues 2-3, 12 May, Pages 105-111

Mendonça, F. (2002) *Clima e criminalidade: ensaio analítico da correlação entre temperatura do ar e a incidência da criminalidade urbana* Curitiba Editora da UFPR

Menegat, R. (2008) *A emergência da tecnourbesfera e os novos desafios da geologia urbana* In: Machado, R. (Ed.). 2008. As ciências da terra e sua importância para a humanidade. A contribuição brasileira para o ano internacional do Planeta Terra. São Paulo, Sociedade Brasileira de Geologia, pp. 75-92

Meyer, R. P. M.; Grostein, M. D.; Biderman, C. (2004). *São Paulo Metrópole* In: São Paulo. Editor University of São Paulo.

Milano, M., Dalcin, E. (2000) *Arborização de Vias Públicas* In: Light, Rio de Janeiro

Minke G., (2000): *Dächer begrünen: einfach und wirkungsvoll* In: Ökobuch Verlag, Staufen bei Freiburg

Miranda, R., Milde L., Bichara, A., Cornell, S. (1993) *Daily Characterization of Air Temperature and Relative Humidity Profiles an a Cacoa Plantation*

Moffat and Schiller (1981) *Landscape Design that Saves Energy* In: Morrow and Co., New York

Monteiro, L. M., Alucci, M. P. (2005) *Índices de conforto térmico em espaços abertos* In: parte 1 & 2, ENCAC 2005

Monteiro, L. M., Alucci, M. P. (2006) *Calibration of outdoor thermal comfort models* In: R. Compagnon, P. Haefeli and W. Weber (eds.), Proc. of 23rd PLEA Conf., Geneva, Switzerland, 2006, vol. I, pp. 515-22

Monteiro, E. Z., Kowaltowski, D. C. C. K. (2007) *Visions for open spaces in owner-built housing areas*

Monteiro, L. M. (2008) *Modelos Preditivos de Conforto Térmico: Quantificação de Relações entre Variáveis Microclimáticas e de Sensação Térmica para Avaliação e Projeto de Espaços Abertos*

Morancho, A. B. (2003) *A hedonic valuation of urban green areas* In: Landscape and Urban Planning 66 35–41

Morengo J.A., Rogers E. (2001): *Present and past inter-hemispheric climate linkages in the Americas and their societal effects* In: New York Academic 2001, Press. Pp 31-49

Mota, J.A. (2006) *O Valor da Natureza – Economia e política dos recursos naturais* In: 2nd edition Garamond Universitaria

Mõttus, M.; Sulev, M., Lang, M. (2006) *Estimation of crown volume for a geometric radiation model from detailed measurements of tree structure* In: Ecological modelling 1 9 8 506–514

Müller, M. (1983): *Handbuch ausgewählter Klimastationen der Erde* In: Universität Trier, Online: www.stadtklima.de <access on 27th of June 2009>

MVRDV (1999) Metacity / Datatown 010 Publishers

Nakamura, Y.; Oke, T. R. (1988): *Wind, temperature and stability conditions in an east-west oriented urban canyon* In: Atmospheric Environment 22(12): 2691–2700

Netzband, M. Banzhaf, E., Weiland, U. (2006) *Remote sensing for Megacities Research* In: 1st EARSeL Workshop of the SIG Urban Remote Sensing Humboldt-Universität zu Berlin, 2-3 March

Ng E., Katzschner, L., Wang, U., Mulder, J. (2007) *Towards Formulating an Urban Climatic Map for High Density Cities - an experience from Hong Kong* In: PLEA

Nijenhuis, W; De Vriers, N. (2000) *Eating Brazil* In: Rotterdam 010 Publishers, Nowak, D. J.; Rowntree, Rowan A. (1991) *Quantifying the Role of Urban Forests in Removing Atmospheric Carbon Dioxide* In: Journal of Arboriculture, 17 (10). October 1, 1991. p.269.

Nowak, D. J. (1994). *Urban forest structure: the state of Chicago's urban forest* In: McPherson, E.G., Nowak, D.J., Rowntree, R.A., eds. Chicago's urban forest ecosystem: results of the Chicago Urban Forest Climate Project. Gen. Tech. Rep. NE-186. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 3-18,140-164.Online: www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/scanned/OCR/ne_gtr186a.pdf <access on 27th of June 2009>

Nowak, D. J. (2003) *U.S. Forest Service Unpublished* In: City specific data produced for American Forests

Oke, T. R. (1987) *Boundary Layer Climates* 2nd Edition, Methuen

Oke, T. R. (1988) *The urban Energy Balance Progress* In: Physical Geography 12(4): 471-508.)

Oke, T. R. (1989) *The micrometeorology of the urban forest* In: Phil. Trans. Royal Society London, vol. B324, pp. 335-49

Oliveira, L., Page, P. (2008) *Urban Age City Survey* Online: http://www.urban-age.net/0_downloads/archive/_SA/10_NewsPaper_Essay_Oliveira-Page.pdf <access on 27th of June 2009>

Oliveira, O. (2006) *Lina Bo Bardi – Sutis Substâncias da Arquitetura* Romano Guerra Editora Ltda São Paulo

Ong, B.L (2003) *Green plot ratio: an ecological measure for architecture and urban planning* In: Landscape and Urban Planning 63 (2003) 197–211

Ottani, D. A. B., Szmrecsányi M.I. (1997) *Cidades Jardins – a busca do equilíbrio social e ambiental 1898-1998* In: Fundação Bienal de São Paulo, 1997 3ª Bienal Internacional de Arquitetura

Padhilha, V (2006) *Shopping Center – A catedral das mercadorias* Bomtempo Editorial/São Paulo

Pauliet, S., Duhme, F., (2000) *Assessing the environmental performance of land cover types for urban planning* In: Landscape Urban Plann. 52, 1–20.

Pedlowski, M., DaSilva, V. A. C., Adell, J. J. C., Heynen, N. (2002) *Urban forests and urban inequality in Campos dos Goytacazes, Rio de Janeiro, Brazil* In: Urban Ecosystems 6:9.20

Peper, P.J., McPherson, E. G. (1998) *Comparison of five methods for estimating leaf area index of open grown deciduous trees* In: Journal of Arboriculture 24 (2): March

Peper, P.J., McPherson, E.G. (2003) *Evaluation of four methods for estimating leaf area of isolated trees* In: Urban Forestry & Urban Greening Volume 2, Issue 1, 2003, Pages 19-29

Phattaralerphong, J., Sinoquet H. (2004) *A method for 3D reconstruction of tree canopy volume from photographs: assessment from 3D digitised plants* In: 4th International Workshop on Functional-Structural Plant Models, 7-11 june 2004 – Montpellier, France Edited by C. Godin et al., pp. 36-39

Pielke, R. A.; Cotton, W. R.; Walko, L. R.; Tremback, C. J.; Lyons, W. A.; Grasso, L. D.; Nicholls, M. E.; Moran, M. D.; Wesley, D. A.; Lee, T. J.; Copeland, J. H. (1992) *A comprehensive meteorological modeling system – RAMS* In: Meteorol. Atmos. Phys., v. 49, p. 69-91

Pietrobon, E. C., Resende, A. S., Gonzalez, M. F. (1999) *Tecnologia apropriada para a determinação de transparência arbórea através da luminância e do tratamento computacional de imagens*

Pietrobon, E. C. (1999) *Luz e Calor no ambiente construído escolar e o sombreamento arbóro: Conflito ou compromisso com a conservação de energia* In: Florianópolis, Doctor thesis Post-graduate course Federal University of Santa Catarina

PNUMA / SVMA, IPT (2004) *GEO cidade de São Paulo: panorama do meio ambiente São Paulo PNUMA*
Online: http://portal.prefeitura.sp.gov.br/secretarias/meio_ambiente/projetos_e_acoes/0004

PRODAM (1997) Secretaria das Finanças Companhia de Processamento de Dados do Município de São Paulo

Rachid, C., Couto, H. T. Z. (1999) *Study of the efficiency of two street trees inventory* *systems in São Carlos - SP, Brazil* In: Scientia Forestalis n. 56, p. 59-68, dez.

Rees, W., Wacknagel, M. (1992) *Ecological footprint and appropriated carrying capacity. Measuring the natural capital requirements of the human economy* In: Contribution to the 2nd Meeting of the International Society for Ecological Economicx „Insvesting in natural capital" in Stockholm, 3./4.8.1992

Reis, N. G. (2006) *Urbanização Dispersa e Mudanças no Tecido Urbano* Edusp

Remund, J., Lang, R., Kunz, S. (1997) Meteonorm, Version 3.0. Meteotest, Bern, 1997

Rivero, R. (1985) *Arquitetura e Clima* UFRGS, Porto Alegre DC Sagra Luzzatto

Roaf, S., Crichton, D., Fergus, N. (2007) *Adapting Buildings and Cities for Climate Change* In: A 21st Century Survival Guide pp 234

Robba, F, Macedo, S. S. (2003) *Praças Brasileiras* São Paulo Edusp, ISBN 85-314-065

Robinette, G. O. (1972) *Plants and their environmental functions* In: Washington, DC: Department of the Interior, National Park Service, 1972. 141 p.

Rolnik, R. (2008) *São Paulo – Eine chronologische Stadtgeschichte* In: Arch+ 190 Stadtarchitektur São Paulo – Ausblick auf ein soziales Raumkonzept

Romero, S. (2000) *Destination: São Paulo* In: Metropolis Magazine, October http://www.metropolismag.com/html/content_1000/sao.htm <access on 27th of June 2009>

Romero, M. A. B. (2001) *Arquitetura Bioclimática do Espaço Público* Editora Universidade de Brasília, Coleção Arquitetura e Urbanismo, ISBN 85-230-0652-4

Rosenzweig, C., Solecki, W. D. (Eds.) (2001) *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change* In: Metro East Coast, Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. Columbia Earth Institute, New York.

Ross, J., Ross, V., Koppel, A. (2000) *Estimation of leaf area and its vertical distribution during growth period* In: Agri. Forrest Met. 101, 237-246

Rowntree, R. (1986) *Ecology of the urban forest — introduction to part II* In: Urban Ecology 9, 229–243

Saint Hilaire, A. (1940) *Viagem à Província de São Paulo* In: São Paulo, Martins, 1940. (p. 218).

Saito I., Ishihara O., Katayama T. (1990) *Study of the effect of green areas on the thermal environment in an urban area* In: Energy and Buildings 15-16: 443-446.

Sanders, R. A. (1984) *Urban vegetation impacts on the urban hydrology of Dayton, Ohio* In: Urban Ecology 9. 361-376

Santos, J., Tavares, R., Amorim, J. H., Miranda, I. (2004) *Estudo do efeito da vegetação na dispersão de poluentes em zonas urbanas* In: University of Aveiro, Portugal, Departamento de Ambiente e Ordenamento http://www2.dao.ua.pt/gemac/resources/8aCNA_Efeito_da_Vegetacao_na_dispersao_de_poluentes_2004.pdf <access on 27th of June 2009>

Schilling V. K. (1990) *A parameterization for modeling the meteorological effects of tall forests – A case study of a large clearing* In: Boundary Layer Meteorology 55, 238-304

Schmidt, M (2003) *Rain Water Harvesting* In: Sustainable Revitalization of Tropical Cities InWent Laar and Knecht (Editors)

Schroeder, H., C. Lewis (1991) *Psychological benefits and costs of urban forests.* In P.D. Rodbell (ed.) Alliances for Community Trees Proceedings of The Fifth National Urban Forest Conference. 12-17 November 1991, Los Angeles, California pp 66-68. The American Forestry Association, Washington, D.C.263 p.

Scott, M (2006) *Beating the Heat in the World's big cities* Online (Interview with Stuart Gaffin) http://earthobservatory.nasa.gov/Features/GreenRoof/printall.php <access on 27th of June 2009>

Scurlock, J. M. O., Asner, G. P., Gower, S. T. (2001) Worldwide Historical Estimates of Leaf Area Index 1932–2000 Online: http://www.osti.gov/bridge <access on 27th of June 2009>

Shahidan, M. F., Salleh, E., Mustafa, K. M. S (2007) *Effects of Tree Canopies on Solar Radiation Filtration*

Sharma, M. R. (1977) *Study of Thermal Effects of Climate and Building on Human*

Comfort with Special Reference to India In: Ph.D. Thesis Agra University India Bureau of Indian Standards (Editor)

Sharma, M.R., Sharafat, A. (1986) *Tropical Summer* In: Index--a Study of Thermal Comfort of Indian Subjects in Building and Environment, Vol. 21, No. 1, pp. 11-24

Shashua-Bar L., Hoffman M. E. (2000) *Vegetation as a climatic component in the design of an urban street* In: Energy and Buildings 31: 221-235.

Shashua-Bar, L.; Hoffman, M. E. (2004) *Quantitative evaluation of passive cooling of the UCL microclimate in hot regions in summer* In: case study: urban streets and courtyards with trees, Building and Environment, vol. 39, pp. 1087-99

Shieh, L. (2006) *Briefing Book MIT Design Studio*
Online: http://stellar.mit.edu/S/project/saopaulo/materials.html <access on 27th of June 2009>

Sigueira V. B. (2001) *Espaços da Arte Brasileira* In: Burle Marx Cosac & Naify Edições, São Paulo ISBN 85-7503-089-2

Silva, A. C. S. B, Sattler, M. A., Lamberts, R. (1995) *Zoneamento Bioclimático Brasileiro para fins de edificação* In: III Encontro Nacional Conforto do Ambiente Construído.

Silva, D. F. F.; Pizetta, P. U. C.; Almeida, J. B. S. A. et al. (2002) Banco de dados relacional para cadastro, avaliação e manejo da arborização em vias públicas Revista Árvore, Viçosa-MG, v. 26, n. 5, p. 629-642, 2002.
http://www.scielo.br/pdf/rarv/v26n5/a14v26n5.pdf <access on 27th of June 2009>

Silva, M. A. V. (2000) *A Atmosfera* In: Instituto Nacional de Meteorologia (Ed). Meteorologia e Climatologia. v. I, Brasília: Gráfica e Editora Stilo. p. 111-146

Silva, M.V. (2005) *Naturalismo e Biologização das Cidade na Constituição da Idéia de Meio Ambiente Urbano* Master thesis University of São Paulo - FAU/ USP 2005

Silva, M. V. (2006) *Detritos da Civilização: Eugenia e as Cidades no Brasil* http://www.vitruvius.com.br/arquitextos/arq000/esp235.asp <access on 27th of June 2009>

Simpson J. R., McPherson E. G.(1995) *Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento* In: Atmospheric Environment Volume 32, Issue 1, January 1998, Pages 69-74 Conference on the Benefits of the Urban Forest

Smith, W.H. (1990) *Air polluition and forests* In: Springer-Vertag, New York, NY. 618 p.

Spangenberg, J. (2004) *Improvement of Urban Climate in Tropical Metropolis* In: A case study in Maracanã / Rio de Janeiro, M. Eng. Thesis, University of Applied Sciences, Cologne, Germany. http://www.basis-id.de/science <access on 27th of June 2009>

Spangenberg, J.; Shinzato, P.; Johansson, E.; Duarte, D. (2007) *The Impact of Urban Vegetation on Microclimate in Hot Humid* In: São Paulo, Proc. of 24th Conf. on Passive and Low Energy Architecture (PLEA), Singapore, 22-24 November

Spangenberg, J. (2008). *Retroinvovação – Enverdecimento Urbano: Uma Antítese ao Aquecimento* In: First published in AU-Arquitetura & Urbanismo Year 23, No. 167

Spangenberg, J.; Shinzato, P.; Johansson, E.; Duarte, D. (2008) *Simulation of the influence of vegetation on microclimate and thermal comfort in the City of São Paulo* In: Revista da Sociedade Brasileira de Arborização Urbana ISSN 1980-7694

Spengler, O. (1922) *Der Untergang des Abendlandes* In: 4. München, p.105.
Spix, J. B. Von; Martius, K. F. P. von. (1823) *Reise in Brasilien auf Befehl Sr. Majestät Maximiliean Joseph I, Königs von Baiern in den Jahren 1817 bis 1820* In: München: M. Lindauer, 1823-1831 in Corrêa , P. L. (2003) “Iconografia Paulistana do século XIX” (ed. Capivara)

Stadt, K. J. and Lieffers, V. J (2000) *Mixlight: a flexible light transmission model for mixed-species forest stands* In: Agri. Forrest Met.,102, 235-252

Stuiver, M. (2006) *The retro side of innovation and it’s potential for regime change in agriculture in between the Local and the Global* In: Confronting Complexity in the Contemporary Agri-Food Sector, edited by Terry Marsden and Jonathan Murdoch, (Elsevier)

SVMA - Secretaria Municipal do Verde e Meio Ambiente (2000) *Atlas Ambiental do Município de São Paulo* Secretaria de Planejamento, Prefeitura do Município de São Paulo, 2000 http://atlasambiental.prefeitura.sp.gov.br/ <access on 27th of June 2009>

SVMA - Secretaria Municipal do Verde e do Meio Ambiente (2005) *Manual técnico de arborização urbana* (2nd edition) http://ww2.prefeitura.sp.gov.br//arquivos/secretarias/meio_ambiente/manual_arborizacao.pdf <access on 27th of June 2009>

Tay, K.S. (1989) *Mega-Cities in the Tropics* In: Towards an Architectural Agenda for the Future. Institute of Southeast Asian Studies (ISEAS), Singapore.

Taha, H. (1997) *Urban Climates and Heat Islands: Albedo, Evapotranspiration and Anthropogenic Heat* In: Energy and Buildings 25, p 99-103

Tarifa, J.R., Azevedo, T. R. (2001) *Os climas na cidade de São Paulo – Teoria e prática São Paulo* In: Pró-reitoria de Cultura e Extensão. USP: Laboratório de Climatologia. FFLCH (GEOUSP – Coleção Novos Caminhos, 4).

Taylor, A. F., Kuo, F. E., Sullivan, W. C. (2001) *Coping with ADD: The Surprising Connection to Green Play Setting*” In: Environment and Behavior, 33(1), 54-77

Thompson J. W., Soving K. (2000) *Sustainable Landscape Construction – A Guide to Green Building outdoors* In: Island Press Washington D. C., Covelo, Calfornia (USP 712 T379s e.3)

Tremback, C. J., Walko, R. L. (1997) *The Regional Atmospheric Modeling System (RAMS): development for parallel processing computer architectures* In: Third RAMS Users’ Workshop. Echuca, Victoria, Australia

Trigueiro, A. (2005) *Mundo sustentável – Abrindo espaço na mídia para um planeta em transformção* Editora Globo, S.A. (p. 146)

Ulrich, R. S., Simons, R.F., Losito, B. D., Fiorito, E., Miles, M. A., Zelson, M. (1991) *Stress recovery during exposure to natural an urban environments*. In: Journal of Environmental Psychology. 11:201-230

UNCED (1992) *Agenda 21*

USDA - United States Department of Agriculture (2006) *Tools for assessing and managing Community Forests* itree http://www.itreetools.org <access on 27th of June 2009>

UWYO (2007). http://weather.uwyo.edu/upperair/sounding.html <access on 27th of June 2009>

Vaz, L. F., Knierbein, S., Guerra, M. W (2006) *Der öffentliche Raum in der Planungspolitik – Studien aus Rio de Janeiro und Berlin* Verlag der Bauhaus Universität Weimar

Velasco, G. D. N. (2003) *Arborização viária x sistemas de distribuição de energia elétrica: avaliação dos custos das podas e levantamento de problemas fitotécnicos* In: Master Thesis, USP Esalq

Velasco, G. D. N. (2007) *Potencial da arborização viária na redução do consumo de energia elétrica: definição de três áreas na cidade de São Paulo - SP aplicação de questionários, levantamento de fatores ambientais e estimativa de Graus-Hora de calor* Doctorate thesis Escola Superior de Agricultura Luiz de Queiroz

Vester, F. (1986) *Ein Baum ist mehr als ein Baum* In: Kösel Verlag

Vignola, R. J. (2005) *A arborização de vias públicas e a paisagem urbana: caso da cidade de São Paulo* Master Thesis FAUUSP

Von Stulpnagel, A., M. Horbert and H. Sukopp (1990) *The importance of vegetation for urban climate.* In H. Sukoop, S.Hejoy, and I. Kowarik (eds.). Urban Ecology: Plants and Plant Communities in Urban Environment. Pp. 175-193. SPB Academic Publishing by Hague, Netherlands, 282 p.

Wakefield, E. G. (1849) *A View of the Art of Colonialization* In: Reprints of Economic Classics Augustus M. Kelley Publishers, New York 1969 S. L.

Watson, D. J. (1947) *Comparative physiological studies on growth of field crops: I. Variation in net assimilation rate and leaf area between species and varieties, and within and between years* Annals of Botany, v.11, p.41-76

Weinstock, M. (2006) *Self-organisation and material constructions* In: John Wiley & Sons, Ltd Online: http://www3.interscience.wiley.com/journal/112653729/abstract?CRETRY=1&SRETRY=0

Weizsäcker, E.U. v., Lovins, A. B. (1995) *Faktor Vier Doppelter Wohlstand - halbierter Naturverbrauch* Droemer Knaur

Wilheim, J. (1991) *Services urbains et gestion de I’environnement à São Paulo* In: Cahiers du Brésil Contemporain,16, S. 65-75. Paris.

Williamson T. R., Erell E. (2001) *Thermal Performance Simulation and the urban* *microclimate* In: Seventh International IBPSA Conference Rio de Janeiro,Brazil August 13-15

Wines, J. (2000) *Grüne Architektur* Benedikt Taschen Verlag GmbH, Köln

Wong, H. N., Jusuf S. K. (2007) *GIS-based greenery evaluation on campus master plan* In: Landscape and Urban PlanningVolume 84, Issue 2, 6 February 2008, Pages 166-182

Xiao, Q., McPherson, E. G. , Simpson, J. R., Ustin, S. L. (1998) *Rainfall interception by Sacramento's urban forest* In: Journal of Arboriculture 24(4): 235-244.

Yeang, K. (2000) *The Green Skyscraper - The Basis for Designing Sustainable Intensive Buildings* In: Prestel Verlag

Yu, C., Nyuk Hien, W. (2006) *Thermal benefits of City Parks* In: Energy and Buildings 38, p.105-120

Zendron, R. (1999) *Glossar – Es ist natürlich alles künstlich* In: Künstlerforum International *Künstler als Gärtner* Modern Nature: O.K. Symosium 6 Ruppichteroth

Literature cited from newspapers

Abbud, A. (2007) *São Paulo precisa ter um plano de arborização* In: Estado de São Paulo 4th of May 2007 H4 Morar Bem Interview with Benedito Abbud

Anauate, C. (2006) *Área verde pode dobrar* In: Jornal da Tarde (JT) 10th of May 2006 pg.5a

Brito, A (2008) *Brasil possui uma 'Itapu atrasada' em novas usinas* In: Folha de São Paulo5th of June 2008 B1 Dinheiro

Carranca, A. (2007) *O que você tem com isso? – Saiba que medidas ajudam reduzir a emissão* In: Journal da Tarde 4th of February 2007 4A JT Cidade

Carrasco, W. (2007) *O verde aprisionado* In: Veja, 21st of March 2007

Cenofanti, L.M.C. and Brancatelli, R. (2006) *As maiores enchentes de São Paulo* In: Veja year 38, n. 22, ed. 1907, 01st of June 2005.

Duran, S. (2006) *Delivery de árvore: ligue e peça uma na sua rua* In: O Estado de S.Paulo 20/09/2006 Online: http://txt.estado.com.br/editorias/2006/09/20/cid-1.93.3.20060920.28.1.xml <access on 25th of June 2009>

Editorial Destak (2008) *Ibirapuera, USP e Horto estão entre as 7 mais poluídos* In: Destak 13th of June

Estado de São Paulo (2007) *SP precisa de 162 milhões de árvores para neutralizar* CO_2 In: Estado de São Paulo, 08 th of December 2007 Focas/ Aquecimento Local H3

Giannasi, I. (2007) *Valor sobre na vizinhança do parque* In: Estado de São Paulo 4th of May 2007 H6 Especial Morar bem

Gregório, E. (2006) *Além do cinza, metrópole tem muito VERDE* in RSVP, No. 24 year 2.

Lutterbach, M. (2006) *Colhendo frutos - Terrenos abandonados viram hortas coletivas* In: Vida Simples March 2007
http://vidasimples.abril.com.br/edicoes/051/mente_aberta/conteudo_235819.shtml

Pereira, R.A. (2003) *Cobertura vegetal é um terço da ideal* (Folha de São Paulo 02 of December 2003) online http://www1.folha.uol.com.br/folha/treinamento/aquijazsaopaulo/te0212200307.shtml
02/12/2003

Sacks, O. (2009) *Darwin e o significado das Flores* In: Piauí_28 3rd year, January 2009, pg. 48

Sangiovanni, R. (2009) *Poluição acelera morte de 20 pessoas por dia em São Paulo* In: Folha de São Paulo 5th of March 2009 (Front Page)

Soares, A. (2007) *Ilhas de Calor fazem temperatura variar até 12 graus dentro de SP* In: 9th of September 2007 Estado de São Paulo Cidades/ Metrópole

Veiga, E. (2007*) Da Noruega à Mongólia – Atlas mostra quais são os melhores e os piores bairros da capital para morar* In: Veja 12th of November 2007, year 40 No. 36 p.42

Vieira, V.R. (2007) *70% trocariam automóvel por transporte público de qualidade* In: Destak 11th of October 2007 (Title & pg. 2)

Zonta, N (2004) *O charme natural dos prédios verdes* In: Estado de São Paulo 7th of September 2004 Caderno Cidades Urbanismo

A I - INTERVIEW WITH ARCHITECT OSCAR NIEMEYER

Brazil's most famous architect Oscar Niemeyer, then ninety-nine years old and considered a living legend, was interviewed for this work because he cites *Nature* (and landscape, see Andreas, 2003) as most important inspirations for his typical walk-in concrete sculptures. On the other hand some of his works have been criticized for being sparse of vegetation. Niemeyer's answers were received in Portuguese via email on Thursday, 23rd of Aug 2007 15:12:40 -03:00h and translated by the author.

Spangenberg: Regarding urbanization in megacities like São Paulo you said: "How to improve São Paulo? Only by knocking down about two blocks and making a garden. That is to recover lost space" and "It is important to be modest. It is the way of looking upward and to notice that nothing is so important. If we believe in nature and that everything comes from nature and everything transforms through her.... " (Revista Bravo! September 2003 "Pessimismo Humanista")

I would like to verify the relationship between nature and your architecture (remembering Le Corbusier's words: "Oscar, you have the mountains of Rio

Fig. A1: Literally green references in Niemeyers oevre -Palácio Itamataí in Brasília (above left), Casa das Canoas in Rio de Janeiro (above right) and Bath in Potsdam (below) in their eyes" and your narrative on the Botanical Garden of Rio): The nature in (your) architecture today is purely formal or also integrated with the physical environment?

Niemeyer: For me architecture has to take the nature that it involves into account. The areas, the spaces closest of the architecture are part of it. The nature of the soil, the inclinations that appear at the place where a building should be built, are also part of the architecture, in my view.

Then to avoid, to the maximum, in the buildings that I project, cuts in the terrain, underground areas, etc. Many times, or almost always, a more uneven terrain leads us to a different solution that detaches architectural work and values it. In the house that I projected for me in Rio, at Canoas Road, it was possible, without altering the inclinations of the terrain, to project the living rooms on top and the rooms below.

Spangenberg: Do you think integration between the human constructions and nature (in the form of vegetation) would it be viable today to create groups of buildings that are more human and less technical in Brazil? Can you describe or draw an idea regarding that?

Niemeyer: Yes, of course. In the constructions close to the sea, even when it is several buildings, the existent panorama is so beautiful that the concern is always to seek a solution that allows all to enjoy it.

Spangenberg: Thank you very much!

[Translated by the author]

Spangenberg: A respeito da urbanização em megacidades como São Paulo o Senhor falou: *"Melhorar São Paulo, como? Só pondo abaixo uns dois quarterões e fazendo um jardim. Isso é recuperar o espaço perdido"* e *"E importante ser modesto. É o jeito de olhar para cima e perceber que nada é tão importante. Se a gente acredita na natureza e que tudo veio da natureza e que todo nela se transforma...."* (in Revista BRAVO! Setembro de 2003 "Pessimismo Humanista")

Eu gostaria de confirmar a relação entre a natureza e a arquitetura do Senhor (lembrando das palavras de Le Corbusier: "Oscar, você tem as montanhas do Rio nos seus olhos" e os seus contos sobre o Jardim Botânico do Rio): A natureza na (sua) arquitetura hoje seria puramente formal ou também integrada ao meio físico?

Niemeyer: Para mim a arquitetura tem de levar em conta a natureza que a envolve. As áreas, os espaços mais próximos da arquitetura dela fazem parte.

A natureza do solo, as inclinações que aparecem no local onde deve ser construído um edifício fazem parte também, a meu ver, da arquitetura.

Daí evitar, ao máximo, nos edifícios que projeto, cortes no terreno, áreas subterrâneas, etc. Muitas vezes, ou quase sempre, um terreno mais acidentado nos leva a uma solução diferente que destaca a obra arquitetônica e a valoriza.

Na casa que projetei para mim no Rio, na estrada das Canoas, foi possível, sem alterar as inclinações do terreno, prever as salas em cima e os quartos embaixo.

Spangenberg: O senhor acha que uma integração entre as construções humanas e a natureza (em forma de vegetação) seria viável hoje para criar conjuntos mais humanos e menos técnicos no Brasil? O senhor pode descrever ou desenhar uma idéia a respeito disso?

Niemeyer: É claro que sim. Nas construções junto ao mar, mesmo quando se trata de vários edifícios, o panorama existente é tão bonito que a preocupação é sempre procurar uma solução que permita a todos dele usufruir.

Spangenberg: Muito obrigado!

[Original]

A II - INTERVIEW WITH SOPHIE BONJOUR (WHO)

Dear Sir,

Concerning your enquiry about the existence of a reference for the WHO recommendation on the “12 m² green space per inhabitant”:

We are aware this has been quoted before, however, we do not know the source. Our in-house experts in the field have never been able to find out where it comes from, and this is not a WHO recommendation they would be aware of.

Hope it helps,

Kind regards

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A II - ENVI-MET VEGETATION MODEL

This annex is a translation of chapter 5 ("Das Vegetationsmodell" - The Vegetation Model) of an updated version (reviewed 24th of April 2004) of PhD dissertation of Bruse, M. (1999): Die Auswirkung kleinskaliger Umweltgestaltung auf das Mikroklima (The Impact of small-scale environmental design on the micro-climate). The original available on the internet on the page http://www.envi-met.de/documents/Envimet30.PDF (Document Title: Bleeding Edge ENVImet 3.0) According to the author certain sections may be out of date.

5. The vegetation model

The integration of vegetation into micro-scale grid models like ENVI-met necessitated some expansions of the model concept. In contrast to the afore defined surfaces, on with which essentially the local atmospheric frame conditions control the condition of the surface and the exchange processes with the surroundings, the biological behavior of the organism of plants is an additional control mechanism. Therefore it is not possible, to consider the individual grid boxes with vegetation separately from each other, instead the reference to the respective plant must be maintained.

Besides from the interfaces which all objects in ENVI-met possess with their surrounding, the vegetation model provides the following information:

- Temperature of leaf surfaces
- Turbulent exchange of sensitive heat between atmosphere and leaf surface
- Vapor flux (transpiration and evaporation as well as condensation) at the leaf surfaces
- Interception of liquid water in the foliage as well as dripping of excessive water on the soil surface

5.1 Parameterizations in the micro-climate model

The vegetation module developed here simplifies a plant to a one-dimensional column with standardized height and/ or depth respectively. The area of z/zp = [0,+1] describes the part of the plant above ground part (canopy) of the plant, while the area z/z r = [-1, 0] describes the part which lies below the ground (roots). The most important parameter for the description of the real plant shape alongside with the absolute plant height z_p and the root depth - z_r is the density distribution of the leafs, as well as the density distribution of the roots in the ground. The leaf distribution is represented by the Leaf Area Density LAD [m² leaf surface per m³ crown volume]. In the ground, his concept was assumed analogously, so that the Root Area Density RAD becomes the main parameter. The parameters of density at 10 base-height-points each, are z/z_p = 0.1, 0.2 ..1.0 and z/z_t = -0.1,-0.2. - 1.0 within the plant column which become, considering the real plant height and root depth pre-determined in the area input file (.in), the corresponding grid-boxes in the model. For big plants, like for example trees, a standardized plant profile is assigned to various grid-points in the model, while with very small plants, like for example grass, several data points fall into one grid box. The LAD-values defined in the area input file (.in are assigned.

In order to improve the resolution of small plants the lowest grid-box of the atmospheric sub-model is divided into 5 partial boxes with ΔZ = 0.2Δz. Through this procedure, it as also is big possible, to deal with as well with very small plants as with large plants within a uniform model scheme.

Beside of the general plant geometry, for each plant type a series of physiological parameters must be given:

Among these are:

- minimal stomata-resistance $r_{s,min}$
- type of the plant (deciduous tree, conifer, grass) for the definition of the leaf geometry
- Leaf albedo in the short-wave area range $_{af}$

Other factors, like the emissivity of leafs and the fractions of the radiation transmitted through the leaf are set constant. All plant parameters referring to plants are composed in one data base and are coupled at the start of the simulation with the pre-determined configuration.

Table 6 shows a selection different vegetation types: trees (T1-T7), hedges (H) and Grass (G). This data was taken from Groß (1991) and Mix. al. (1994) or estimated. The profile of the Root Area Density is set to 0.1 for all plants in the data base due lack of better information. As already indicated, these data does not yet contain any information on the respective plant height. The absolute height for the different plants is stored as additional information in the data base.

5.2 Determination of the turbulent fluxes of the leaf surface

5.2.1 Turbulent impulse exchange

The impulse loss of leafs is already considered in the flow model through

ID	z/z_p 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	Art	D	K/S
T1	0.04	0.06	0.07	0.11	0.13	0.15	0.14	0.13	0.10	0.00	LB	m	○
T2	0.10	0.14	0.18	0.27	0.33	0.37	0.36	0.33	0.25	0.00	LB	d	○
T3	0.08	0.08	0.08	0.08	0.25	1.15	1.06	1.05	0.92	0.00	LB	d	•
T4	0.15	0.15	0.15	0.15	0.65	2.15	2.18	2.05	1.72	0.00	LB	sd	•
T5	0.00	0.00	0.15	0.15	0.65	2.15	2.18	2.05	1.72	0.00	LB	sd	•
T6	0.40	0.60	0.55	0.50	0.45	0.40	0.25	0.20	0.15	0.10	NB	m	○
T7	0.00	0.00	0.01	0.08	0.25	1.15	1.06	1.05	0.92	0.00	LB	d	•
H	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	L	sd	
G	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	G	m	

Table 6: *Composition more different vegetation types used in the model. Modified after Groß (1991) and Mix et al. (1994).**Type: LB=deciduous tree, NB=conifer, L=deciduous scrub, G=grass, D: m=mean density, d=dense, sd= dense, K/S:.=none Differentiation trunk and crown tree, • = distinguished crown tree***

additional sink terms. Therefore on the side the vegetation model no further treatment is the impulse flux is necessary.

5.2.2 Turbulent exchange of sensitive heat

The temperature flux between the leaf surface and the surrounding air is a function of the temperature difference and the aerodynamic resistance of the leaf surface r_a. This concept corresponds to the approach applied in section 3.3.5 S.40 after Monin-Obhukov. Between the aerodynamic resistance r_a and the drag coefficients exists the following linear relationship:

$$r_a = \frac{1}{c_d \cdot u_{w+1}} \qquad (5.1)$$

With a given leaf surface temperature T_f, the turbulent flux of sensible heat is:

$$J_{f,h} = 1.1 r_a^{-1}(T_f - T_a) \qquad (5.2)$$

The resistance r_a is represented according to Braden (1982) as a function of the wind velocity and two vegetation-specific parameters A and D:

$$r_a = A\sqrt{\frac{D}{\max(W_f, 0.05)}} \qquad (5.3)$$

For deciduous trees and grasses A=87 √sm^{-1}, for conifers A=200 √sm^{-1}, is applied, D stands for the average leaf diameter and is 0.02 m for conifers and grasses and 0.15 m for deciduous trees (Schilling, 1990; Naot und Mahrer, 1989).

For windless situations r_a is not defined with, therefore the minimal wind speed is set to 0.05 ms^{-1}. A formulation for free convection on vegetation elements is not available at the moment.

5.2.3 Turbulent vapor flux

The calculation of the vapor exchange between leaf surface and the air is more complex than the determination of the heat transfer, because the vapor flux is split into an evaporation term $Jf_{,evap}$ and a transpiration term $Jf_{,trans}$:

$$J_{f,v} = J_{f,evap} + J_{f,trans} \qquad (5.4)$$

Hereof, the former depends only on the moisture difference between leaf surface and the ambient air, while the latter additionally depends on complex plant-physiological processes. On the other hand it is possible to parameterize both terms based on the transfer resistance. The following expression stands for the evaporation and/ or condensation respectively:

$$J_{f,evap} = r_a^{-1} \begin{cases} f_w \Delta q \\ \Delta q \end{cases} \qquad (5.5)$$

If Δ > 0 (Evaporation)
If Δ < 0 (Condensation)

The aerodynamic resistance r_a applied here corresponds with the resistance value calculated in (5.3).

The transpiration flux is additionally regulated by the leaf stomata and results in the formula:

$$J_{f,trans} = \begin{cases} (r_a + r_s)^{-1}(1 - f_w)\Delta q \\ 0 \end{cases} \qquad (5.6)$$

if Δq > 0 (Transpiration)
if Δq < 0

In both cases the moisture difference Δq between the saturation q* at leaf temperature T_f and the moisture of the ambient air q_a has to be calculated:

$$\Delta q = q_*(T_f) - q_a \qquad (5.7)$$

The proportion of the moist leaf area of the total leaf area is calculated according to Deardorff (1978):

$$f_w = \left(\frac{W_{dew}}{W_{dew,max}}\right)^{2/3} \qquad (5.8)$$

This function considers that (liquid) water W_{dew} forms droplets on the leaf surfaces, that this water is not equally distributed on the available surfaces and that it comes to the formation of moistened and dry areas (on the leaf surfaces), if $W_{dew,max}$ (=LAD Δz*0.2 kgm^{-2}) was below the saturation (dew point). The application of f_w in (5.5) provides that the evaporation occurs only from the moistened proportion of the leaf surfaces, while transpiration occurs only from the dry parts of the leaf surfaces.

The stomata resistance r_s describes the regulating influence of the stomatous cells on the vapor exchange with the air. The real value of r_s at a certain moment is a complex function of different parameters like solar radiation, water availability, the composition of the air and the general physiological condition of the plant (compare Mihailovic und Rajkovic , 1994).

In the vegetation model this influence spectrum is limited and simplified to three factors: the current short-wave solar radiation, the water availability in the ground and the general condition of the plant. In a future version this module will be replaced by more complex approaches which can better describe the stomata behavior (Jones,1992).

The current stomata resistance can consequentially be calculated in the following way (see for example, Deardorff, 1978):

$$r_s = r_{s,min}\left[\frac{R_{kw,max}}{0.03R_{kw,max} + R_{kw}} + f_s + f_{wilt}\right]$$

(5.9)

Where $rs_{,min}$, is the minimal stomata resistance which varies that from plant to plant and from season to season. In table 7 some example resistance values for different vegetation types are compiled. In the vegetation model it is assumed that it only depends on the plant type and as well that $rs_{,min}$ has no seasonal variations.

5.2.3.1 The Influence of the radiation on r_s

The maximal available short-wave incoming radiation $R_{kw,max}$ is defined in the model as the radiation, which incidences at midday on a non-shaded, randomly orientated leaf. R_{kw} is the short-wave radiation which effectively incidences on the leaf incident and consequently depends on the position of the sun and shadowing.

This parameterization of radiation can only approximately reflect the behavior of the stomata. Specifically leafs which are always shaded or exposed to extreme solar radiation the stomata will show a different behavior in reality.

5.2.3.2 Influence of the season on r_s

The factor f_s describes roughly, whether leafs still actively participate in the water exchange or whether they do not transpire anymore due to general condition of the plant. During of the growth season f_s=0, in autumn, for grasses late summer respectively, f_s=1.

5.2.4 Influence of soil-water availability for plants on r_s

Another important influence on the transpiration of the plant is the availability of soil water in the root area (f_{wilt}). If the water content approaches the permanent wilting point, it becomes increasingly difficult for the plant to withdraw water from the soil through osmotic suction pressure, so that transpiration has to be decreased for the lack of water supply.

The parameterization of this relationship is carried out calculating the relation of the current water content of the soil η and the permanent wilting point η_{wilt}. Here a weighted mean is calculated over the whole root area (zone).

$$f_{wilt} = \frac{1}{N}\sum^{N}\left[\frac{RAD(n)\Delta z(n)}{RAI}\cdot\left(\frac{\eta_{wilt}(n)}{\eta(n)}\right)^2\right]$$

(5.10)

Here the proportion of the root surface, in the layer n, of the total root area is applied as weighting factor. N is the number of the ground layers within the root area and RAI is the Root Area Index with

$$RAI = \int_{-z_r}^{0} RAD(z')dz' \qquad (5.11)$$

Since plants are interpreted as vertical columns, it also is feasible to define vegetation above sealed surfaces. Hereby, for example, overhanging tree crowns can be simulated. In these cases the root area is associated below the sealing layer and locally appropriated.

5.2.5 Special case roof greening (Version V2.5)

From version 2 onward, it is possible to define plants also on roofs. Since no appropriate soil model is available for the water availability which mostly depends on external irrigation the factor f_{wilt} in these cases must be defined in another way. To achieve this, an external Irrigation $Factor_{water}$ is defined, which can vary between 1 (full irrigation) and just above 0 (extreme dryness). The integration into the model is through the allocation:

$$f_{wilt} = \frac{\eta_{wilt}(n=-T)}{water \cdot \eta_s(n=-T)}$$

(5.12)

Here, the fictitious soil moisture, in the case of full irrigation, is set equal to the saturation degree of the substratum η_s. of the lowest grid box in the soil model. The selection of the reference box is arbitrary, since also the field capacity η_{wilt} is defined on the basis of this box. It must only be guaranteed merely that no sealing material was defined in the selected box, which is most probably given in the deepest ground layer.

Vegetation	Albedo a_f	$r_{s,min}$
Corn/ crop (young)	0,30	200
Corn/ crop (old)	0,25	400
Sugar cane	0,20	200-400
Conifer stands	0,15	600
Deciduous forest	0,25	400
Grass general	0,20	200
Swamp	0,20	200

Table 7: *Albedo and minimal Stomata resistance of different vegetation types (after Tjernström,1989)*

5.2.5.1 Distribution of the liquid water on the plant

The current water amount W_{dew} on leaf surfaces required in (5.6) can change during the course of the simulation time through drying, dew moistening or dripping of water. Consequently it is necessary, to update the proportion of the liquid water on the leaf surfaces in periodical intervals.

The water balance of a one-dimensional plant layer with the thickness of Δz yields from the balance from the water gains through vapor condensation and additionally supplied drip water P↓ (rainwater or runoff from higher vegetation layers) minus the water loss through evaporation, or drip water running off into deeper layers P↓.

$$\frac{\partial W_{dew}}{\partial t} = -\rho \int_{z}^{z+\Delta z} \mathrm{LAD}(z') J_{f,evapo} dz' + P^{\downarrow} - P_{\downarrow} \tag{5.13}$$

If the water share on the leafs in one box exceeds the maximum value of $W_{dew,max,}$ W_{dew} = Wdew,max, and the water in excess is transferred to the lower vegetation layers, applying the drip water term P↓. In the lowest vegetation layer the residual water rest is conducted to the soil.

5.3 Determination of the leaf surface temperature

The energy balance of a single leaf can be described as:

$$0 = R_{kw,net} + R_{lw,net} - H_f - LE_f + Q_s \tag{5.14}$$

The sensitive and latent heat flux on the leaf surface emerges from (5.2) as well as (5.4) and (5.5):

$$\begin{aligned} H_f &= c_p \rho J_{f,h} \\ LE_f &= \rho L(T_f)(J_{f,trans} + J_{f,evap}) \end{aligned} \tag{5.15}$$

For the determination of the energy balance of the single leaf, initially the short-wave radiation fluxes at a height z need to be calculated as described in chapter 3.4 p. 48ff. The short-wave radiation absorbed at the leaf surface $R_{kw,net}$ is:

$$R_{kw,net}(z) = (F \cdot R_{kw,dir}(z) + R_{kw,dif}(z))(1 - a_f - tr_f) \tag{5.16}$$

where t_{rf} is the radiation share, transmitted through the leaf. According to Oke (1984) 0.3 can be applied as a mean value over all wavelengths. The factor F describes the influence of the leaf orientation on the quantity of the absorbed radiation and is set to 0.5 for randomly orientated leafs. The long-wave radiation balance of the leaf is:

$$\begin{aligned} R_{lw,net}(z, T_f) = \varepsilon_f R^{\downarrow}_{lw}(z) + \varepsilon_f R^{\uparrow}_{lw}(z) - \\ 2\varepsilon_f \sigma T_f^4 + \varepsilon_f \left(R^{\leftrightarrow}_{lw}(z) - (1 - \sigma_{svf}) \sigma T_f^4\right) \end{aligned} \tag{5.17}$$

The different components of the long-wave radiation were already introduced and considered in the sections 3.4.3 and 3.4.4 according to the situation, also the radiation exchange with subsequent upward and downward vegetation layers and/ or shielding buildings.

The emissivity of the leafs ε_f is kept constant with a mean value of 0.96 (Pielke, 1984). The albedo of the leafs varies from plant to plant and is readout from the data (see table 7).

As last unknown term in (5.10) remains the internal energy storage in the leaf cormus Q_s. Inclán *et al.* (1996) assert that the internal heat storage of the leaf is an important component of the energy balance, especially during sunrise and sunset. However, for this no suitable parameterizations do exist and the influence on the overall results appears marginal, so that simplified

$$Q_s = \mathrm{const} = 0 \tag{5.18}$$

is assumed.

Numerical studies with the model have shown that the calculation of the leaf surface temperature responds sensitive to different radiation parameterizations. Especially the calculation of the long-wave exchange processes between buildings, vegetation and atmosphere during the night has shown very susceptible towards marginal changes so that finally the parameterization was chosen which produced the most plausible results.

5.4 Coupling with the atmosphere model

The heat and moisture flux at the leaf surface is connected through the source terms Q_θ and Q_q with the prognostic equations of the atmospheric model. For the prognostic temperature equation results:

$$Q_\theta(x, y, z) = \mathrm{LAD}(z) \cdot J_{f,h} = \tag{5.19}$$

The source term for the vapor flux is

$$\mathrm{LAD}(z) \cdot 1.1 r_a^{-1} (T_f - \theta(x, y, z)) \tag{5.20}$$

Or respectively

$$Q_q(x, y, z) = \mathrm{LAD}(z) \cdot (J_{f,trans} + J_{f,evap})$$

if Δq ≥ 0 (5.21)
if Δq < 0

5.5 Coupling with the soil model

The water transpired by the plant must be withdrawn from the ground. Therefore the hydrological part of the soil model possesses the local sink terms S_η. The total amount of water transpired by the plant results from the vertical integral of the predicted transpiration fluxes from the different vegetation layers.

$$j^{ges}_{f,trans} = \rho \int_0^{z_p} \mathrm{LAD}(z) J_{f,trans}(z) dz \tag{5.22}$$

According to Hillel (1980), a maximum of 1% of the transported water is incorporated within the plant, so that is assumed that a balance between the transpired water and the water absorption through the roots exists. The water withdrawal in the soil is weighted by the respective root area (surface) in the depth of -z. As an additional weighting factor the hydrological diffusivity of the soil D_η is considered (Pielke, 1984) The demanded water withdrawal S_η at the depth -z then is:

$$S_\eta(-z) = \frac{j^{ges}_{f,trans}}{\rho_w} \left(\frac{\mathrm{RAD}(-z) D_\eta(-z) \Delta z}{\int_{-z_r}^{0} \mathrm{RAD}(-z) D_\eta(-z) dz} \right) \frac{1}{\Delta z} \tag{5.21}$$

A IV - ARTICLE 1: THE IMPACT OF URBAN VEGETATION ON MICROCLIMATE IN HOT HUMID SÃO PAULO

By Jörg Spangenberg[1,2], Paula Shinzato[1], Erik Johansson[1,3] and Denise Duarte[1]

ABSTRACT: Field monitoring in a park, a square and a street canyon on a summer day in São Paulo, Brazil, showed that the park was up to 2K cooler than the square and the canyon. The effect of adding shading trees to the street canyon was simulated for the same day using the numerical model ENVI-met. The simulations showed that incorporating street trees in the urban canyon had a limited cooling effect on the air temperature (up to 1.1K), but led to a significant cooling of the street surface (up to 12K) as well as a great reduction of the mean radiant temperature at pedestrian height (up to 24K). Although the trees lowered the wind speed, the heat stress was mitigated considerably as the physiologically equivalent temperature (PET) was reduced by up to 12K, mainly due to shading.

Keywords: urban vegetation, urban microclimate, numerical simulation, pedestrian comfort

1. INTRODUCTION

Vegetation is an important design element in improving urban microclimate and outdoor thermal comfort in urban spaces in hot climates [1]. Due to urbanization, however, vegetation is scarce in many tropical cities. The main benefits of vegetation in hot climates are reduced solar radiation and lower air temperature due to shading and evapotranspiration [2]. Lower air temperatures are essential both to improve thermal comfort conditions of pedestrians and to limit energy use for cooling.

This paper shows results from an ongoing study of the benefits of vegetation in the city of São Paulo, Brazil. This 19 million sprawling metropolis is characterised by a heterogeneous urban structure as well as by an uneven distribution of urban green. It is located at 23°32'S, 46°37'W, 60km from the sea at 720-850m altitude. The city's summer climate is hot and humid with mean temperatures between 22°C and 30°C, but temperatures above 30°C are common.

2. METHODOLOGY

Climate monitoring was carried out on 19th of December 2006, a typical summer day, in the central area of Luz. An 8 ha park, a square and an urban canyon were compared in order to examine the effect of the park's vegetation. Three meteorological stations (Huger WM 918 and 968, as well as ELE MM900) were used to measure air temperature, humidity and wind speed simultaneously at 1.10m height at the three locations.

The urban canyon, which is located in a dense area with an average height-to-width ratio of 2.2 and almost devoid of vegetation, was chosen for a parametric study using the microclimate model ENVI-met [3]. The ENVI-met model, which was chosen due to its advanced approach on plant-atmosphere interactions, was carefully calibrated with the measurement results by adjusting various input parameters related to local climate and urban surface properties so that similar daily temperature and humidity curves were achieved. The comparison between measured and simulated air temperature is shown in Figure 1.

In addition to the actual situation, two different greening scenarios were simulated, one with less dense street trees (T1) and another with a much denser tree canopy (T2). The leaf area indices (LAI) for T1 and T2 were 1 m²/m² and 5 m²/m² respectively Both tree types were 10m high with canopies covering the entire street. Both parametric tree models had ellipsoid leaf area distributions with maximum Leaf Area Densities (LAD) located in the middle of the crowns. The attenuation of solar radiation at midday was 39,3% for T1 and 91.9% for T2.

The aim was to evaluate how the LAD of the two tree canopy types influenced air temperature, surface temperature, humidity, wind speed and, consequently, thermal comfort. The Physiologically Equivalent Temperature (PET) was applied to this study. This comfort index was calibrated by Monteiro and Alucci [4] for open spaces in the city of São Paulo interviewing approximately 2.000 people adapted to local conditions.

3. RESULTS

The simulated results are shown for the

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crossing between the east-west and north-south oriented street canyons.

3.1 Measured air temperature and humidity

Comparing the measured cooling effect of the park with the treeless street canyon (see Fig. 1), ambient air temperature profiles in the park were, on average, 1.5K cooler with peaks up to about 2.5K at around noon. The relative humidity was about 10% higher in the park than in the other two sites.

3.2 Simulated air temperatures

Figure 1 shows that the canyon covered with less dense (T1) and dense tree canopies (T2) have, on average, 0.5K and 1.1K lower air temperatures respectively than the case without trees.

3.3 Humidity and wind speed

The relative humidity rises only slightly due to the incorporation of trees in the street canyon (less than 5%). The high-density canopy causes a 1-2% higher RH than the low-density canopy.

The wind speed simulated by ENVI-met is clearly affected by the trees. Although the studied trees have no leaves between ground level and 3 m height, the wind speed at pedestrian height (1.5 m) is reduced from about 0.86 m/s (no trees) to about 0.80 m/s (low-density canopy T1) and to 0.47 m/s (high-density canopy T2), respectively. Thus, canopies with low LAD reduce wind speed considerably less than trees with high LAD.

3.4 Surface and Mean Radiant Temperatures (MRT)

During the hours when the street receives solar radiation (from 12:00 to 15:00), the trees have a great impact by lowering the surface temperature by up to 5K and 12K for the low-density (T1) and high-density tree canopy (T2), respectively.

The mean radiant temperature is the parameter mostly affected by shading trees. The vegetation has a huge impact by lowering the MRT by up to 11K and 24K for the low-density (T1) and high-density canopy (T2), respectively. The reduction in MRT through shading includes both less received direct, diffuse and reflected short-wave radiation from the sun and lower surface temperatures and thereby lower thermal (long-wave) radiation from urban surfaces.

3.5 Physiologically Equivalent Temperature (PET)

PET is highly influenced by the presence of shading trees. Figure 2 shows how PET varies at pedestrian height for the three cases (no trees, low-density canopy (T1) and high-density canopy (T2)). Similarly to the MRT, PET reaches highly uncomfortable conditions between 12:00 and 15:00. The peak is considerably lowered by a low-density canopy (T1) and virtually erased by a high-density canopy (T2).

4. CONCLUSIONS

The results from the simulations presented in this study clearly show that vegetation in the form of trees has a great potential of improving the microclimate and mitigate heat stress in a hot humid climate. We observed a clear tendency of PET to decrease with increasing leaf area, at least up to a LAI of 5 m²/ m². Thus, even in the 21st century, vegetation remains an irreplaceable, sustainable urban element, especially in (sub-)tropical cities.

ACKNOWLEDGEMENTS

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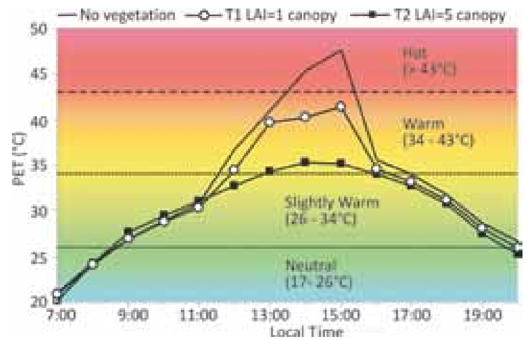
REFERENCES

[1] J. Spangenberg, Improvement of Urban Climate in Tropical Metropolis – A case study in Maracanã/ Rio de Janeiro M. Eng. Thesis, University of Applied Sciences, Cologne, 2004 http://www.basis-id.de/science

[2] H. Akbari, M. Pomerantz and H. Taha, Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas, Solar Energy, vol. 70 (2001), pp. 295-310.

[3] M. Bruse, ENVI-met v. 3, http://www.envi-met.com, 2006

[4] L.M. Monteiro and M.P. Alucci, Calibration of outdoor thermal comfort models. In: R. Compagnon, P. Haefeli and W. Weber (eds.), Proc. of 23rd PLEA Conf., Geneva, Switzerland, 2006, vol. I, pp. 515-22 of vegetated areas is highly dependant on



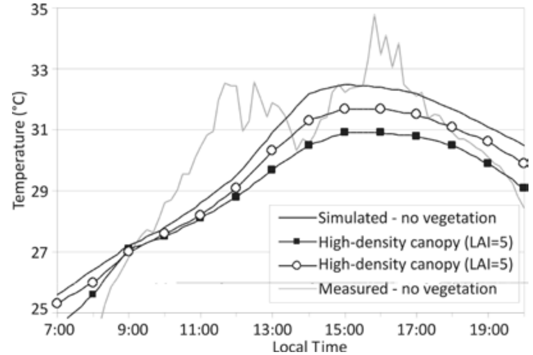


Figure 1 (left): ***Simulated air temperature for the street canyon without trees, with low-density tree canopy and high-density tree canopy. The measured air temperature of the canyon is also shown.***

Figure 2 (right): ***Simulated PET for a street with no vegetation, low-density tree canopy (T1) and high-density canopy (T2). The PET limits for "neutral", "slightly warm", "warm" and "hot" are shown.***

A V - ARTICLE 2: SIMULATION OF THE INFLUENCE OF VEGETATION ON MICROCLIMATE AND THERMAL COMFORT IN THE CITY OF SÃO PAULO

By Jörg Spangenberg[1,2], Paula Shinzato[1], Erik Johansson[1,3] and Denise Duarte[1]

ABSTRACT
The microclimates of a park, a square and a street canyon were measured on a summer day in the city centre of São Paulo, Brazil. The field monitoring showed that the park was up to 2°C cooler than the square and the canyon. The effect of adding shading trees to the street canyon was simulated for the same day using the numerical model ENVI-met. The simulations showed that incorporating street trees in the urban canyon had a limited cooling effect on the air temperature (up to 1.1°C), but led to a significant cooling of the street surface (up to 12°C) as well as a great reduction of the mean radiant temperature at pedestrian height (up to 24°C). Although the trees lowered the wind speed up to 45% of the maximum values, the thermal comfort was improved considerably as the physiologically equivalent temperature (PET) was reduced by up to 12°C.

Keywords: urban vegetation, urban microclimate, numerical simulation, pedestrian thermal comfort

RESUMO
Durante o verão, foram realizadas medições das condições microclimáticas existentes em um parque, uma praça aberta e um *canyon* urbano na cidade de São Paulo. Os resultados do monitoramento de campo indicaram que o parque apresenta temperaturas do ar até 2°C mais baixas do que na praça e no *canyon*. O efeito de novas árvores no *canyon* urbano foi simulado por meio do modelo ENVI-met na mesma data da medição. Os resultados das simulações mostram o efeito do resfriamento da temperatura do ar em até 1.1°C e, por outro lado, uma diminuição da temperatura superficial do pavimento (até 12°C), bem como uma considerável redução na temperatura radiante média no nível do pedestre (até 24°C). Apesar da diminuição da velocidade do vento em até 45% nos valores máximos, o conforto térmico teve uma melhora considerável, uma vez que a temperatura fisiológica equivalente (PET) foi reduzida em até 12°C.

Palavras-chave: vegetação urbana, microclima urbano, simulação numérica, conforto térmico dos pedestres.

INTRODUCTION

In the tropics, the outdoor thermal comfort conditions during daytime are often far above acceptable comfort standards due to intense solar radiation and high solar elevations (Ali-Toudert and Mayer, 2007; Johansson, 2006). While the urban heat island is less of a problem in temperate climates, it is unwanted in low and mid latitude cities as it contributes to increase the cooling load and results in increased energy use (Taha, 1997).

Vegetation is an important design element in improving urban microclimate and outdoor thermal comfort in urban spaces in hot climates (Spangenberg, 2004). Due to urbanization, however, vegetation is scarce in many tropical cities. There has often been a tendency to replace natural vegetation and permeable soils with impervious surfaces such as asphalt and concrete, which leads to more sensible than latent heat flux (Emmanuel, 2005). In urban streets, vegetation is often considered a problem for several reasons. For example, trees are costly to maintain, their canopies often interfere with overhead telephone and electric lines and their roots may destroy pavements and underground sewers.

The use of vegetation in hot climates

The main benefits of vegetation in hot climates are reduced solar radiation and lower air temperature due to shading and evapotranspiration. Lower air temperatures are essential both to improve thermal comfort conditions of pedestrians and to limit energy use for cooling. According to Akbari et al. (2001) peak energy demand in the USA rises 2–4% for every 1°C increase in maximum air temperature.

Among other factors, the effect of vegetation on the microclimate depends on the size of the vegetated area. While the cooling effect on the air temperature is limited for a single tree or a small group of street trees (Oke, 1989), larger areas such as parks can have a significant cooling effect (Yu and Hien, 2006). The evapotranspiration of vegetated areas is highly dependant on soil humidity; for dry soils, which are common in urban areas due to sealing of the ground, evapotranspiration cooling will be limited (Oke, 1989).

There are also negative effects of vegetation in warm climates. One drawback with trees is that they block the wind; a deciduous tree may reduce wind speeds by 30-40% (Ali-Toudert and Mayer, 2007). Trees with large canopies will also reduce nocturnal cooling as they block some of the net outgoing long-wave radiation.

Several recent studies have shown that vegetation is beneficial in lowering air temperatures, in providing shade and in improving thermal comfort. Field measurements by Shashua-Bar and Hoffman (2004) showed that some tree-aligned streets and boulevards in the Tel-Aviv area, Israel, had 1–2.5°C lower air temperatures than non-vegetated streets at the hottest part of the day (15:00 h). Applying the simulation software ENVI-met (Bruse, 2006) to the climate of Thessaloniki, Greece, Chatzidimitriou et al. (2005) found small temperature decrease for tree-aligned streets (less than 1°C), but up to 20°C lower surface temperatures and more than 40°C lower mean radiant temperatures. The cooling effect was found to increase with rising number of trees. In the hot dry climate of Ghardaia, Algeria, Ali-Toudert and Mayer (2007) found that shading trees could improve the thermal comfort in streets considerably. In another simulation study of different greening scenarios using ENVI-met in Rio de Janeiro, Brazil, Spangenberg (2004) found that an increased amount of urban green (tree cover of 30% of the ground and 100% green roofs) could nearly re-create the comfortable conditions of a natural forest.

Urban vegetation in São Paulo, Brazil

This paper shows preliminary results from an ongoing study of the benefits of vegetation in the city of São Paulo, Brazil. The research includes field measurements during the hot humid summer to compare the microclimates of a park, a square and an urban canyon as well as numerical simulations of the effect of vegetation on microclimate using ENVI-met (Bruse, 2006). There are several recent studies simulating the effect of vegetation in warm climates with ENVI-met. These studies have, however, been either focussing on air temperature in warm and dry climates (Ali-Toudert and Mayer, 2005; Ali-Toudert and Mayer, 2007; Chatzidimitriou et al., 2005) or only treated effects on the air temperature and not thermal comfort itself (Jusuf et al., 2006; Spangenberg, 2004; Yu and Hien, 2006).

The objective of this research is to study the effect of shading trees with different leaf densities on the microclimate and outdoor thermal comfort in public spaces. From the output data provided by ENVI-met it is possible to estimate thermal comfort by calculating the Physiologically Equivalent Temperature (PET).

Materials and Methods

Area of Study

The city of São Paulo

The city of São Paulo is located at 23°32'S, 46°37'W, 60km from the sea. The altitude varies between 720m and 850m. The city's climate is characterised by hot, humid summers with air temperatures varying between mean minima of 22°C and mean maxima of 30°C and mild winters with temperatures between mean minima of 10°C and mean maxima of 22°C.

São Paulo is a sprawling South American megacity, which's metropolitan area houses almost 19 million inhabitants, distributed in an area of 8051km^2. Based on reports from the Municipal Environmental Agency (SVMA, 2004), São Paulo's economy represents 31% of the national Gross Domestic Product (GDP). However, this economic development has led to a significant degradation of the urban environment, a common situation in many large cities in developing countries.

Today, São Paulo is characterised by a heterogeneous urban structure, which has been caused by the rapid growth of the city during the last century. One of the effects of this growth is the social conflict and contrast of high-rise office towers close to poor informal settlements (favelas). According to the architect Oscar Niemeyer, "The first lesson São Paulo offers is that no city should grow so arbitrarily" and "the second lesson of São Paulo is that its people, and the people of cities in poor countries elsewhere, should have the right to a habitat that is more graceful" (Romero, 2000).

The distribution of vegetated areas is non-uniform in the city. Only the wealthiest boroughs are characterised by large amount of vegetation and tree-aligned streets, while the downtown areas of Brás and Santa Cecília are almost devoid of vegetation (SVMA, 2004).The Environmental Atlas of São Paulo (SVMA, 2004) includes a map showing surface temperatures in the city of São Paulo. The highest temperatures were found in the central area without green areas and the lowest in urban parks. Similar temperature patterns were found by Duarte and Souza (2005).

To improve the situation, the City Hall is investing in tree planting programs and several linear parks, intending to increase the vegetated areas.

On-site Measurements

The central area of São Paulo is formed by the Old Town (Sé), the New Town (República) and another 10 boroughs (Meyer et al., 2004). In the downtown area, there are seven urban parks.

For decades, downtown has suffered a continuous degradation process and has gradually been abandoned by its residents. The metropolitan area of São Paulo experiences simultaneously massive urban sprawl in its peripheries and population decrease in its central parts (the population of the central borough of República diminished by 28% between 1980 and 1999). Today, some downtown districts have a population density of less than 70 inhab/ha (IBGE, 2000) in spite of a high built density.

To change this negative trend, downtown has been the focus of revitalization efforts with several urban projects organized by the local government. The recent initiatives show the special interest to promote a public discussion for possible transformations of the existing urban structure. One of them is the project *Nova Luz* (New Luz), which intends to implement new commercial and residential buildings on the one hand and preserve the existing architectural patrimony on the other hand. However, vegetation does not play a major role in this renewal process.

This study focuses on the area of Luz (Figs. 1 and 2), which is situated in the city centre.

Since 2004, LABAUT has been studying the central area of the city as part of a partnership with University of Cambridge and University of East London (LABAUT, 2006). The project Sustainable Urban Spaces has explored new environmental approaches for the revitalization of abandoned parts in central areas.

Methodology

On-site Measurements

Climate monitoring was carried out on 19th of December 2006 in the area of Luz (Figs. 1 and 2). This day can be considered a typical hot summer day: clear sky conditions in the morning, partly overcast sky in the afternoon and rain in the evening (see Fig. 4). The main goal of these measurements was to create an initial database for air temperature, relative humidity, solar radiation, surface temperature, wind direction and wind speed for the summer period.

Three main types of urban spaces

Figure 1. a) Street life in the Luz area (photos of square, left, and street canyon, right).
b) The measurement equipment used in the urban canyon. Source: LABAUT

were defined for the measurements: a park, an open air square and an urban canyon. These three areas were chosen considering the main characteristics of the site and its surroundings (Fig. 2). The particular interest was to compare the effect of vegetation in the park with the other two situations. The sky view factor, that is, the amount of the sky seen from a point on the ground, of the three sites varies considerably (Fig. 3).

Figure 2. Location of the three measurement points in Luz borough.

Point 1 = park, point 2 = canyon and point 3 = square. Source: Google Earth

(1) (2) (3)

Figure 3. Hemispheric pictures of the sky view taken with a Nikon 4500 equipped with a 180° fish eye lens for park (1), canyon (2) and open square (3). Source: LABAUT

The canyon is located in a dense area with 5-10 storeys high commercial buildings. The street has an intense flux of vehicles and pedestrians attracted by the local commerce of electro-electronics devices (Fig. 1a). In addition to this critical situation, the thermal comfort is poor. The average block size in Luz is 60m by 100m. The street canyon has an average width of 12m and the building height is on average 26m (corresponding to eight-storey buildings) which gives a height to width ratio (H/W) of 0.5. There are very few trees in the street due to narrow sidewalks and problems with aerial electric cables and telephone lines. The open square, which has white stone paving (Portuguese pavement), is more exposed to direct solar radiation than the other sites due to lack of vegetation and shading.

Three meteorological stations (Huger WM 918 and 968, as well as ELE MM900) were used to measure air temperature, humidity and wind speed simultaneously at 1.10m height at the three locations (Fig. 1b). All measurements were recorded on data loggers every ten minutes between 7:00 and 19:00 local daylight saving/ summer time.

On the square, additionally global solar radiation was measured with a pyranometer. Surface temperatures of various construction materials and natural surfaces were measured on the square using an infrared thermometer TFA 31.1108. During the intervals of the measurements interviews with pedestrians regarding their thermal comfort sensation and their opinion on benefits and problems with vegetation in the city were carried out.

Thermal Comfort Surveys

To support a study aiming at developing a local comfort index for São Paulo, surveys on the subjectively perceived outdoor thermal comfort were executed in the three aforementioned locations. Since this study is not concluded yet, the Physiologically Equivalent Temperature (PET, Höppe, 1999) was adopted in this paper to evaluate and compare the results. PET, which is designed for outdoor conditions and is based on a steady-state heat balance equation of the human body, takes all environmental parameters that affect thermal comfort – air temperature, mean radiant temperature, humidity and wind speed – into account. Personal factors such as clothing insulation and the level of activity are, however, not included. PET has recently been calibrated against subjective comfort votes in the climate of São Paulo by Monteiro and Alucci (2006) who interviewed approximately 2.000 people adapted to local conditions.

Microclimate simulations

The micro scale model ENVI-met (Bruse, 2006) was chosen for this study due to its advanced approach on plant-atmosphere interactions in cities. The numerical model simulates aerodynamics, thermodynamics and the radiation balance in complex urban structures with resolutions (grid-sizes) between 0.5m and 10.0m according to position of the sun, urban geometry, vegetation, soils and various construction materials by solving thermodynamic and plant physiological equations.

The building section of the model has shown some limitations, since the same properties (such as albedo and U-value) are applied equally to all walls and roofs respectively. Further, the heat storage term for the buildings, which calculates the time lag, is not included in the energy balance of the building surfaces. Due to this fact, the thermal mass of vertical constructions, which causes delayed heat dissipation, is not taken into account for buildings, as it is for ground paving and soils.

The input data for the simulations are shown in Table 1 and the input area file is shown in Fig. 4a. The solar radiation, which is calculated depending on latitude, was slightly over-estimated by ENVI-met for São Paulo conditions and was therefore decreased to 90%. The only additional climate data (not derived from local measurements) was that for specific humidity at 2500m, which was obtained from local airport soundings at Campo de Marte (ca. 3.3km North of the site), available from the homepage of University of Wyoming (UWYO, 2007).

As recommended (Bruse, 2006), 48 hours simulations were used to pass the initial transient time in order to obtain results that are more reliable. In the preliminary simulations, both the average air temperature and the diurnal amplitude were underestimated. Therefore, some of the input data had to be adjusted to achieve better correlation with the measured results. The temperature course of the model has shown significant sensibility to wind speed. The diurnal amplitude tends to increase with decreased wind speed. The measured wind speed varied strongly in direction and speed throughout the day. The average mean wind speed measured was 1.6m/s, but 0.8m/s was adopted in order to adjust the temperature curve. The initial temperature was increased by 1°C in order to approximate to measured peak values, resulting in a limited correlation between measured and simulated temperature curve in the morning (7:00 – 9:00 h) and in the evening (17:00 – 20:00 h).

Atmosphere	
Start of simulation (h)	**7:00**
Wind speed at 10 m above ground level [m/s]	**0.8**
Wind direction	**170**
Initial temperature of the atmosphere [in degrees Kelvin]	**297**
Specific humidity at 2500 m [g Water/kg air]	**9.0**
Solar adjustment factor	**0.9**
Relative humidity at 2m [%]	**70**
Soils	
Relative humidity in all layers [%]	**25**
Buildings	
Albedo of walls	**0.4**
Albedo of roofs	**0.3**

Table 1. Input configuration data applied in the ENVI-met simulations.

After the calibration process, similar daily temperature and humidity curves were achieved. The comparison between measured and simulated air temperature is shown in Fig. 4b. The calculated coefficient of determination, R^2, between measured and simulated air temperature, based on 79 values, was found to be 0.7487.

To a large extent the urban geometry of a city is characterized by a repetitive element called the urban canyon (Emmanuel, 2005). Consequently, an urban canyon was chosen for a parametric study and the simplified model is shown in Fig. 4a. In addition to the actual situation, two different greening scenarios were simulated, one with less dense street trees (T1) and another with a much denser tree canopy (T2). The leaf area indices (LAI)[5] for T1 and T2 were 1 m^2/m^2 and 5 m^2/m^2 respectively. Both tree types were 10m high with canopies covering the entire street. Both parametric tree models had ellipsoid leaf area distributions with maximum Leaf Area Densities (LAD)[6] located in the middle of the crowns. The attenuation of solar radiation at midday was 39,3% for T1 and 91.9% for T2. The aim was to evaluate how the attenuation of solar radiation of the two tree canopy types influenced air temperature, surface temperature, humidity, wind speed and thermal comfort.

Results and Discussion

Measurement Results

The results shown at Local Time (in this case equal to daylight saving time) of the measurements gave important information about the microclimatic differences among the three urban sites (Fig. 6a). The ambient air temperature profiles show that the cooling effect of the park is on average 2°C compared to the open square with peaks up to 6°C. Compared to the canyon, the temperature of the park is about 2.5°C lower around noon. The relative humidity was about 10% higher in the park than in the other two sites (Fig. 6b). The absolute humidity (g/m^3) is about $1 g/m^3$ higher in the park. The lower temperature and higher humidity in the park is due to shading and evapotranspiration.

Simulation Results

The results are shown for a point in the crossing between the east-west and north-

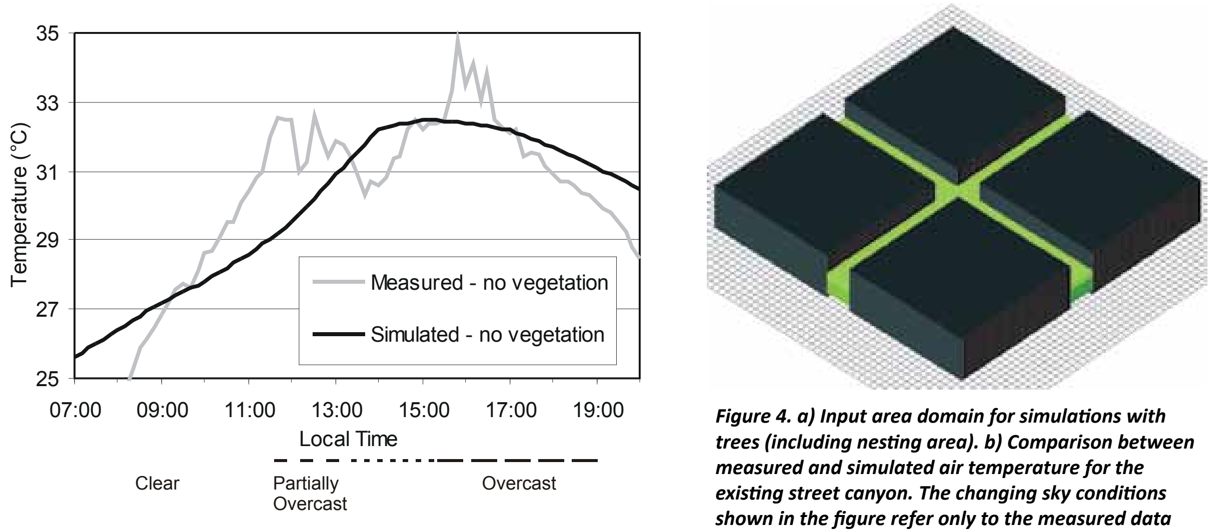


Figure 4. a) Input area domain for simulations with trees (including nesting area). b) Comparison between measured and simulated air temperature for the existing street canyon. The changing sky conditions shown in the figure refer only to the measured data and cannot be simulated with ENVI-met yet.

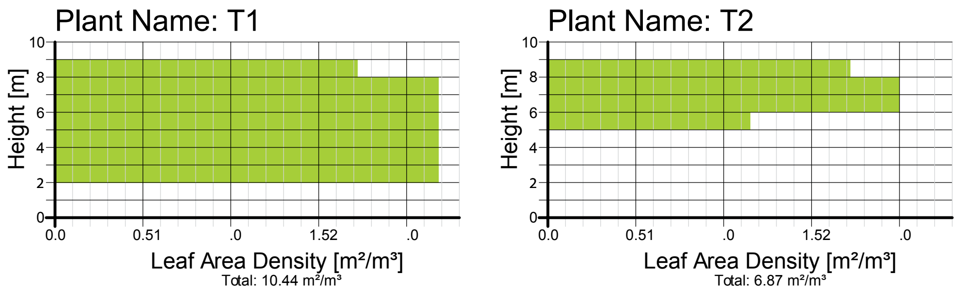


Figure 5. LAD (Leaf Area Density) (m^2/m^3) in 10 layers of the two tree models T1 and T2. T1 has 20% of the Leaf Area Density (LAD) of T2.

[5] The Leaf Area Index (LAI) is defined as the total one-sided leaf surface area (m^2) per unit ground area (m^2)
[6] The Leaf Area Density (LAD) is defined as the total one-sided leaf area (m^2) per unit layer volume (m^3) in each horizontal layer of the tree crown.

south oriented street canyons. All results are shown at Local Time, which in our case is equal to daylight saving time (summer time), that is LST+1 h.Air temperatures.

In Fig. 7a the simulated air temperature is shown for the three cases no trees, trees having a high-density canopy (LAI=5) and trees having a low-density canopy (LAI=1). The canyons covered with less dense (T1) and dense tree canopies (T2) have, on average, 0.5°C and 1.1°C lower air temperatures than the case without tree, respectively.

The fact that street trees have only a limited cooling effect on the air temperature agree fairly well with both field measurements (Shashua-Bar and Hoffman, 2004) and simulation studies (Ali-Toudert and Mayer, 2005; Ali-Toudert and Mayer, 2007; Chatzidimitriou et al., 2005). The effect found in this study is, however, less than that reported by Ali-Toudert and Mayer (2005; 2007), who found cooling effects of up to 1.5°C for a hot-dry city. The reason may be that the air was dryer in their study and hence the cooling effect of evapotranspiration higher.

Surface temperatures

Fig. 7b shows the surface temperature of the asphalted street for the three cases (no trees, low-density canopy and high-density canopy). During the hours when the street receives solar radiation (from 12:00 to 15:00), Fig. 7b shows that the trees have a huge impact on the surface temperature of the ground. The less dense

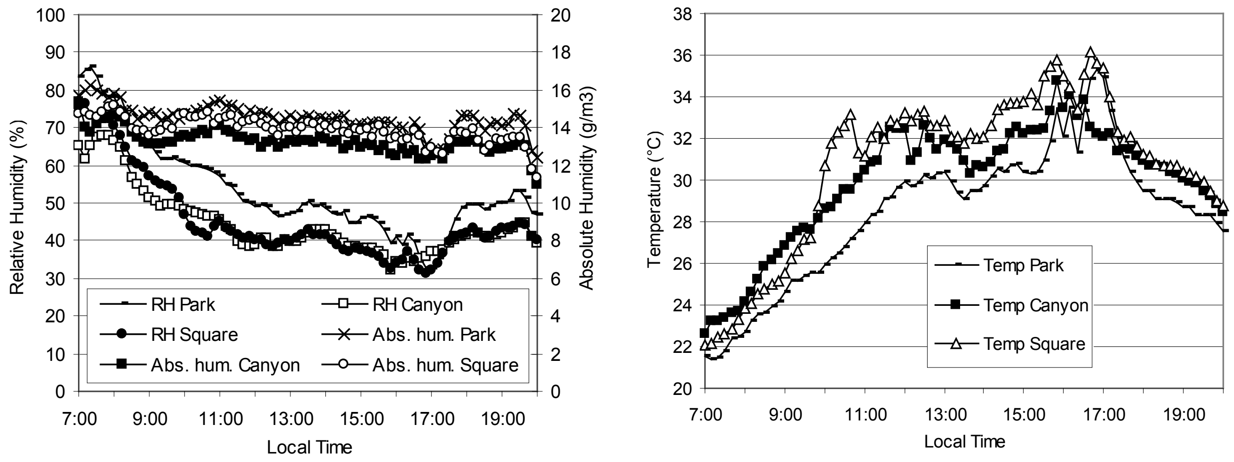


Figure 6. a) Results of air temperature distribution for the park, the open square and the canyon. b) Results of relative and absolute humidity distribution for the park, the open square and the canyon.

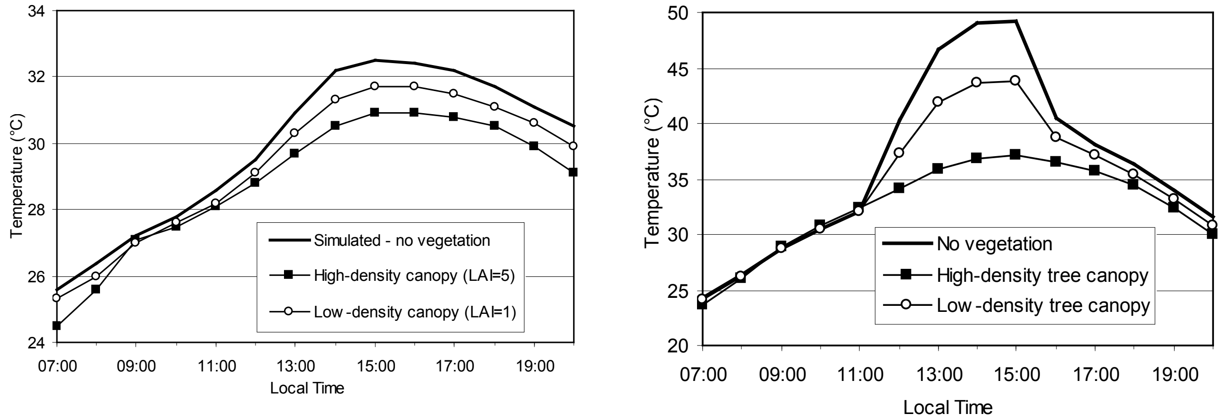


Figure 7. a) Simulated air temperature for the street canyon without trees, with trees having a high-density canopy and with trees having a low-density canopy. b) Simulated street surface temperature for treeless street, street with high-density tree canopies and street with low-density tree canopies.

tree (T1) lowers the temperature by up to 5°C and the high-density tree (T2) by up to 12°C.

The results agree well with Chatzidimitriou et al. (2005), although they report even higher reduction in surface temperatures. The reason may be that they studied a shallower canyon (H/W = 0.5) and thus the temperature of their treeless case was higher than in this study where the canyon is relatively deep (H/W = 2.2).

Mean Radiant Temperature (MRT)

The mean radiant temperature (MRT) is the parameter mostly affected by shading trees. Fig. 8a shows how the MRT varies at pedestrian height for the three cases (no trees, high-density canopy and low-density canopy). During the hours when the street receives solar radiation (from 12:00 to 15:00), Fig. 8a shows that the less dense (T1) and dense (T2) tree canopies lower the MRT by up to 11°C and 24°C respectively. The high-density canopy is considerably more efficient than the low-density canopy.

The reduction in MRT through shading includes both less received direct, diffuse and reflected short-wave radiation from the sun and lower surface temperatures and thereby lower thermal (long-wave) radiation from urban surfaces.

The reductions in MRT found in this study are less than found by Chatzidimitriou et al. (Chatzidimitriou et al., 2005). A probable reason is that they studied a shallower canyon as discussed above.

Humidity

The relative humidity rises only slightly due to the incorporation of trees in the street canyon (less than 5%). The high-density canopy causes a few per cent higher RH than the low-density canopy. The absolute humidity is, however, similar for all cases and very stable, varying from about 12 to 14 g/m³ during the day. The insignificant effect on tree evaporation on humidity found here agrees well with other studies (Ali-Toudert and Mayer, 2005; Ali-Toudert and Mayer, 2007).

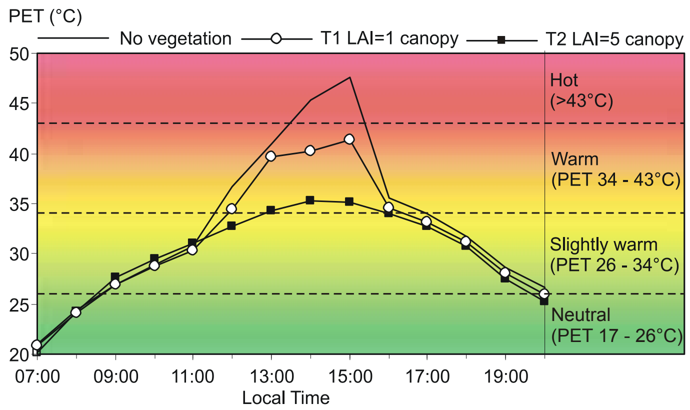
Wind speed

The wind speed simulated by ENVI-met is clearly affected by the trees. Although the studied trees have no leaves between ground level and 3 m height, the wind speed at pedestrian height (1.5 m) is reduced from about 0.86 m/s (no trees) to about 0.80 m/s (high-density canopy) and to 0.47 m/s (low-density canopy), respectively. Thus, canopies with low LADs reduce wind speed considerably less than trees with high LADs.

Physiologically Equivalent Temperature (PET)

The thermal comfort, expressed as the physiologically equivalent temperature (PET), was calculated based on simulated values of air temperature, MRT, relative humidity and wind speed (however, the simulated wind speed was increased again to agree with the measurements).

PET varies significantly between a treeless street canyon and a street covered



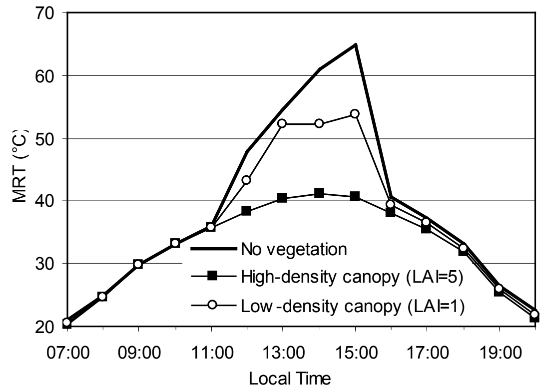


Figure 8. a) Simulated MRT for treeless street, street with high-density tree canopies and street with low-density tree canopies. b) Simulated PET for treeless street, street with high-density tree canopies and street with low-density tree canopies.

with tree canopies. Figure 8b shows how PET varies at pedestrian height for the three cases (no trees, high-density canopy and low-density canopy). Similarly to the MRT, PET reaches highly uncomfortable values between 12:00 and 15:00. This peak is considerably lowered by the less dense trees (T1) and virtually erased by the dense shading trees (T2). Denser trees are thus more efficient although they lower the wind speed more than the less dense trees.

The reductions in PET found in this study (up to 12°C) are less than those presented by Ali-Toudert and Mayer (Ali-Toudert and Mayer, 2005; Ali-Toudert and Mayer, 2007) who found reductions above 20°C. The reason may be that they had a larger proportion of direct solar radiation and thus the trees provided more efficient shade.

CONCLUSIONS

The measurements indicated that the public Luz Park has a cooling effect with around 2°C lower temperatures than its surroundings. The surface temperature measurements also showed that natural surfaces are considerably cooler than commonly used construction materials such as concrete and asphalt.

The results from the simulations presented in this study clearly show that vegetation in the form of trees has a great potential of improving the microclimate and mitigate heat stress in a hot humid climate.

The leaf area index (LAI) and leaf area density (LAD) of the canopy proved to be important metrics, which have a significant influence on the microclimate. The denser the tree canopy (higher LAI and LAD), the lower the air and surface temperatures and the better the thermal comfort for hot-humid climate.

In general, trees provide, under their canopies (locally restricted), significant improvements on thermal comfort principally during midday and in the early afternoon as they provide overhead shading by attenuating the solar radiation. The crucial benefit of shade, resulting in considerably lower mean radiant temperatures, has more influence on the thermal comfort expressed in PET than the decrease of the wind speed. Moreover, trees increase the quality of the public space, also due to other benefits, not included in this study yet, like absorption of rainwater and CO_2 and other air pollutants uptake.

Isolated trees and even rows of trees have a rather small impact on the decrease of air temperatures, and thus, apparently a limited potential for mitigating air temperatures of the urban heat island. Consequently the possibility to improve energy efficiency of buildings by decreasing heat loads is limited. However, the lower surface temperatures of roofs and façades caused by the vegetation will contribute to lower cooling loads (Akbari et al., 2001).

Only the implementation of city-wide changes (from groups of trees to large-scale green space interventions), encouraged by modified building codes and citizens' initiatives, could promote a greener (well distributed vegetation in) São Paulo and mitigation of the urban heat island. For this purpose, even in the 21st century, vegetation remains an irreplaceable urban element. Hence, it is possible, nowadays, due to technological advance to access, to analyse and better understand the impacts of vegetation with the aid of tools like ENVI-met.

Planned Future Work

Future studies include research on different species of local urban street trees, on the importance of tree height, type of tree canopies, leaf area index (LAI) and leaf area density (LAD). Another aim is to adapt the standard ENVI-met plant database to a local plant database. Moreover, the climatically strategically positioning and grouping of trees will be studied.

In future work, other types of urban areas such as squares will be studied as well as different types of parks. In addition, the results of the questionnaire surveys on subjective perception of the thermal environment will be part of the thermal comfort studies.

Since the boundary conditions of the ENVI-met model can hardly be defined correctly based on field measurements, investigations on corrections and nesting with the meso-scale model RAMS (Freitas et al., 2007) has been initialized. Forcing the ENVI-met model may become necessary in future steps of the work process.

To calibrate the model for the conditions of the measurements we are trying to overcome the missing impact of heat storage by allocating materials with increased thermal mass around the buildings on the sidewalks according to a method proposed by Johansson (2006).

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REFERENCES

AKBARI, H.; POMERANTZ, M.; TAHA, H. *Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas.* Solar Energy, Tampa, vol. 70, n. 3, p. 295-310, 2001.

ALI-TOUDERT, F.; MAYER, H. *Thermal comfort in urban streets with trees under hot summer conditions.* In: PLEA 2005 – Passive and Low Energy Architecture, 2005, Beirut. Proceedings PLEA 2005 – Passive and Low Energy Architecture, Beirut: PLEA International, 2005, p. 699-704.

ALI-TOUDERT, F.; MAYER, H. *Effects of asymmetry, galleries, overhanging façades and vegetation on thermal comfort in urban street canyons.* Solar Energy, Tampa, vol. 81, p. 742-754, 2007.

BRUSE, M. *ENVI-met v. 3.0.* Available at: <http://www.envi-met.com>. Accessed 1 July 2007.

CHATZIDIMITRIOU,A.;CHRISSOMALLIDOU, N.; YANNAS, S. *Microclimate modifications of an urban street in northern Greece*. In: PLEA 2005 – Passive and Low Energy Architecture, 2005, Beirut. Proceedings PLEA 2005 – Passive and Low Energy Architecture, Beirut: PLEA International, 2005, p. 689-694.

DUARTE, D.; SOUZA, T. *Urban Occupation Patterns and Microclimates in São Paulo – Brazil.* In: SB 2005. Sustainable Building, 2005, Tokyo. The 2005 World Sustainable Building Conference, 2005.

EMMANUEL, M. R. *An Urban Approach to Climate-Sensitive Design – Strategies for the Tropics.* New York, Spon Press, 2005.

FREITAS, E. D.; ROZOFF, C. M.; COTTON W. R.; SILVA DIAS, P. L. *Interactions of an urban heat island and sea-breeze circulations during winter over the metropolitan area of São Paulo, Brazil*. Boundary-Layer Meteorology, Dordrecht, vol. 122, p. 43–65, 2007.

HÖPPE, P. *The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment.* International Journal of Biometeorology , Dordrecht, vol. 43, p. 71-75, 1999.

IBGE. *Censos Demográficos*, Instituto Brasileiro de Geografia e Estatística (IBGE), 2000.

JOHANSSON, E. *Urban design and outdoor thermal comfort in warm climates – studies in Fez and Colombo,* 2006. Thesis (PhD in architecture), Housing Development & Management, Lund University, Lund, Sweden, 2006.

JUSUF, S. K.; HIEN, W. K.; LA WIN, A. A.; THU, H. K.; NEGARA, T. S.; XUCHAO, W. *Study on effect of greenery in campus area*. In: PLEA 2006 – Passive and Low Energy Architecture, 2006, Geneva. Proceedings PLEA 2006 – Passive and Low Energy Architecture, Geneva: PLEA International, 2006, vol. I, p. 483-488.

LABAUT. *Sustainable Urban Spaces.* Intermediate report: context studies and the strategy for environmental/ sustainable urban design. Colaboração Internacional Brasil-UK. Laboratory of Comfort and Energy Studies – LABAUT, FAUUSP. São Paulo, 2006. (To be published)

MEYER, R. P. M.; GROSTEIN, M. D.; BIDERMAN, C. *São Paulo Metrópole.* Sao Paulo: EDUSP, 2004.

MONTEIRO, L. M. AND ALUCCI, M. P. *Calibration of outdoor thermal comfort models.* In: PLEA 2006 – Passive and Low Energy Architecture, 2006, Geneva. Proceedings PLEA 2006 – Passive and Low Energy Architecture, Geneva: PLEA International, 2006, vol. I, p. 515-522.

OKE, T. R. *The micrometeorology of the urban forest.* Phil. Trans. Royal Society London, London, vol. B324, p. 335-349, 1989.

ROMERO, S. Destination: São Paulo. *Metropolis Magazine,* October 2000. Available at: <http://www.metropolismag.com/html/content_1000/sao.htm>. Accessed 1 July 2007.

SHASHUA-BAR, L.; HOFFMAN, M. E. *Quantitative evaluation of passive cooling of the UCL microclimate in hot regions in summer, case study: urban streets and courtyards with trees.* Building and Environment, Oxford, vol. 39, p. 1087-1099, 2004.

SPANGENBERG, J. *Improvement of Urban Climate in Tropical Metropolis – A case study in Maracanã/ Rio de Janeiro,* Thesis (Master in architecture), University of Applied Sciences, Cologne, Germany, 2004. Available at: < http://www.basis-id.de/science >. Acessed 3 March 2008.

SPANGENBERG, J.; SHINZATO, P.; JOHANSSON, E.; DUARTE, D. (2007). *The Impact of Urban Vegetation on Microclimate in Hot Humid São Paulo,* In: PLEA 2007 – Passive andLow Energy Architecture. 2007, Singapure. Proceedings PLEA 2007 – Passive and Low Energy Architecture, Singapure: PLEA International, 2007.

SÃO PAULO (cidade). Secretaria do Verde e do Meio Ambiente – SVMA. *Atlas ambiental de São Paulo,* Prefeitura da Cidade de São Paulo, 2004.

TAHA, H. *Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat.* Energy and Buildings, Oxford, vol. 25, p. 99-103, 1997.

UWYO. *Soundings.* Available at: <http://weather.uwyo.edu/upperair/sounding.html>. Accessed 1 July 2007.

YU, C; HIEN, W. N. *Thermal benefits of city parks.* Energy and Buildings, Oxford, vol. 38, p. 105-120, 2006.

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Spangenberg, J., Shinzato, P., Johansson, E., Duarte, D. (2008) Simulation of the influence of vegetation on microclimate and thermal comfort in the City of São Paulo, Revista da Sociedade Brasileira de Arborização Urbana ISSN 1980-7694 Online: http://www.revsbau.esalq.usp.br/volume3numero22008/artigos_cientificos.php

Spangenberg, J. (2008) Retroinovação – Enverdecimento Urbano: Uma Antítese ao Aquecimento (Revista AU, Ed. Pini, No. 167, Fevereiro de 2008) Online: http://www.revistaau.com.br/arquitetura-urbanismo/167/artigo72655-1.asp

Hepner, A.,Montes, A., Spangenberg, J., Zumthor, C. (2007): Green Worm, In: Designing at the Edge of the Center (MIT+MACKENZIE+FAUUSP) Imprensa Oficial Online: http://stellar.mit.edu/S/project/saopaulo/materials.html

Spangenberg, J., Shinzato, P, Johansson, E., Duarte, D. (2007) The Impact of Urban Vegetation on Microclimate in Hot Humid São Paulo (PLEA2007 - The 24th Conference on Passive and Low Energy Architecture, Singapore, 22-24 November 2007)

Fretin, D., Bedendo, I., Szabo, L., P., Amodeo, W., Benites, H., Spangenberg, J. (2006): Investigations on a natural ventilation System using the Structure Design of a Building (PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture, Geneva, Switzerland, 6-8 September 2006)

Spangenberg, J. (2005): Simulation of Urban Microclimate in tropical Metropolis´ – Maracanã/ Rio de Janeiro -A Case Study (Kongress Rio5, World Climate & Energy Event, Rio de Janeiro/ Brasil)

Spangenberg, J. (2004): Improvement of Urban Microclimate in tropical Metropolis´ (Melhoramento de clima urbano em Metrópole tropical) Online: www.basis-id/science

Wöhler, T., Nolte, T., Spangenberg J. (2004): Chancen und Risiken für deutsche Architekten in Brasilien (db - Deutsche Bauzeitung 6/ 2004/ Alemanha)

Spangenberg, J. (1999): Explosion tropischer Originalität (DBZ - Deutsche Bauzeitschrift, Bertelsmann-Verlag, Gütersloh) und in „Architekturstudium - und dann?“ (Birkhäuser Verlag, 2003) Online: http://www.baunetz.de/sixcms_4/sixcms/detail.php?object_id=38&area_id=1655&id=94291

Klein S., Milbradt R., Spangenberg J. (1999): Haus mit Eigenschaften (DBZ -Deutsche Bauzeitschrift 2/ 99, Bertelsmann-Verlag, Gütersloh/ Alemanha)