‘Metabolic Impact Analysis’ for urban planning

Paulo Pinho, Vitor Oliveira, Sara Santos, Magda Barbosa

CITTA – Centro de Investigação do Território, Transportes e Ambiente

Faculdade de Engenharia, Universidade do Porto

Rua Roberto Frias 4200-465 Porto, Portugal

E-mail: pcpinho@fe.up.pt, vitorm@fe.up.pt, scruz@fe.up.pt, magdab@fe.up.pt

Abstract

The functioning of current urban systems involves high levels of resource consumption and a huge number of flows. The fundamental concern of this paper is to understand how future urban systems can be designed to be consistently less damaging to the environment. Therefore, its main contribution for the sustainability debate is the design of a methodology for evaluating the urban development process from a metabolic perspective. After a brief introduction to the field of evaluation, it outlines the state-of-the-art on urban planning, urban form, impact assessment, environmental accounting, and urban metabolism, in an attempt to identify theories, concepts, and particularly methods and techniques, that can contribute to the purpose of the article. Based on this literature review – which highlights three particular methods – a set of principles for a metabolic evaluation of the processes of transformation of city-regions is outlined. The Metabolic Impact Analysis is proposed and characterized, its main influences are identified, and the procedure of evaluation is described in considerable detail.

Keywords: evaluation methodology, urban metabolism, impact assessment, urban planning, urban form, urban development

1 Introduction

The concept of urban metabolism helps to understand and analyze the way how societies use energy, materials, water, food, and land, for maintaining and reproducing themselves. Urban systems are a specific form of organizing societies, namely a concentration of economic, reproductive and distributive functions in certain locations, while using and exchanging resources from much larger areas, especially in a global economy context. The way cities and urban areas are being built is greatly influencing the quantities and qualities of resources being used in maintaining urban life. The quantities and the qualities of this exchange with the environmental system are increasingly damaging.

This paper is part of a 3-year European research project, the 'Sustainable Urban Metabolism for Europe' (SUME), funded by the Seventh Framework Programme, involving ten partners from nine countries and two continents. The main goal of the project is to understand how future urban systems can be designed in a way which is consistently less damaging to the environment than the current status. For a detailed description of SUME see Schremmer et al (2010). This article focuses on a particular stage of the SUME project, the design of a methodology for evaluating the urban development process from a metabolic perspective, the MIA.

The first section of the paper, after this brief introduction, presents the fundaments of evaluation activity, focusing then on five fields of knowledge – urban planning, urban form, impact assessment, environmental accounting and energy, and urban metabolism. The review is oriented to the identification and characterization of evaluation methods and techniques for planning practice that relate urban form and urban development with urban metabolism – focusing on the consumption of energy, water, materials and land. Based on the literature review, and particularly on three specific methods – threshold analysis, land suitability analysis, and environmental impact assessment – a set of principles framing the design of the methodology is defined – it should evaluate the urban development process (from a metabolic perspective), focus on plans and projects as fundamental drivers of the urban development process, assess the city wide metabolic impact of the proposals included in plans and projects, have an evaluation rationale provided by the territory, be better suited to short-term (ex-ante or ex-post) analysis although it may address different temporal scales, and deal with the environment in an integrated way. We then move to a characterization of MIA against the background of the Environmental Impact Assessment (EIA). In addition we describe its main components, and structure the evaluation procedure in six main stages. Finally, we present our main conclusions on the design of the methodology and reflect on our future research particularly on the application of MIA in a set of European cities in order to validate it in different geographical and planning contexts.

2 Evaluation

Evaluation is not something new, it has always been an intrinsic part of decision making. Whenever a reasoning actor undertakes a particular course of action, some consideration and assessment of the possible consequences, however intuitive it may be, is an inevitable preliminary to the commitment (Alexander, 2006).

In the absence of a general and consensual vision on the evolution of evaluation theory, many authors converge on the acknowledgment of a shift from a positivist paradigm to a constructivist paradigm. Some describe this evolution in four evaluation generations (Guba and Lincoln 1989; Khakee 1998, 2003). According to Guba and Lincoln (1989) the first generation of evaluation exercises was intended to measure individual attributes, the second generation was geared towards the description of programmes and objectives, the third was dominated by judgments on the contextual values of the object, and the fourth was centred around the negotiation of claims, concerns and issues presented by the different stakeholders. Nevertheless evaluation theory and evaluation practice seem to be two different realities.

Evaluation and each activity under assessment – planning, education, health… – interact and are in constant change. In addition, one of the main challenges of evaluation lies in the lack of a single approach, valid for every situation (Rossi et al, 1999). Accordingly, the evaluator should structure his methodology depending on the specific nature of the situation, and should not follow, in a rigid way, a number of standardized procedures.

In general, the evaluation process comprises three different stages: ex-ante evaluation, taking place in the beginning of the process and promoting the comparison of possible alternatives; on-going evaluation occurring during implementation and enabling shifts in the process according to its conclusions; and finally, ex-post evaluation, taking place in the end of the implementation process and focusing on the results and impacts. Different stages in the process are stressed according to the different activity under assessment.

Another important issue, not consensual in literature, is the role of the evaluator. Undoubtedly, there are advantages, but also disadvantages, in the integration of the evaluator in the team whose work is being assessed. The main advantages of an internal evaluation are fourfold: a greater knowledge on the specific institutional context, a greater probability of adopting the final recommendations, a reduced possibility to look at the assessment exercise as a threat to the institution, and eventually, a reduced use of financial resources. The major disadvantage is the tendency to avoid negative conclusions and to accept the conventional line of thought. The main advantages of an external evaluation may be a greater objectivity in the evaluation, and the facility of external hiring during short periods of time. The most important disadvantages of an external evaluation mirror the main advantages of an internal exercise. Two different possibilities should also be considered, a mixed evaluation, and an internal assessment prepared by an evaluator independent from the planning team.

The design of an evaluation methodology involves three main definitions: the questions, the criteria, and the indicators. The questions, developed by the evaluator, the decision-maker and the main stakeholders, should identify the issues the evaluation will investigate and should be stated in terms such that they can be answered in a useful way involving methods available to the evaluator.

Each of these questions should correspond to, and be synthesized in an evaluation criteria. The assessment of each criterion should involve the use of indicators, from traditional ones – economic, social, and environmental – to integrated approaches.

Finally, the presentation of evaluation results and their use by decisions makers are two crucial stages of the evaluation process. First, it is necessary that the main stakeholders be able to understand the evaluation results. Accordingly, the presentation mechanisms must find the balance between communication and technical knowledge. Second, it should be possible to find the actual utility of evaluation results to the activity under assessment. In fact, the evaluation exercise must establish the terms and the required mechanisms by which a successful utilization may be judged.

3 Literature review

3.1 Urban planning and urban development

3.1.1. Ex-ante evaluation in planning

Planning evaluation has been an established field of research for a considerable number of years. Its development has been closely associated with changes in planning theory and practice as well as in policy analysis and programme evaluation. Planning evaluation most obviously refers to the making of normative judgments about the success of the intervention outcomes of planning or assessing the success of the process of planning (Khakee et al, 2008).

Comprehensive reviews of these methods can be found, for instance, in Lichfield et al (1975), Lichfield (1996), McAllister (1982), and Talen (1996). Drawing on Table 1, taken from Lichfield (1996), the next paragraphs present the most important methods for the ex-ante evaluation of planning. Due to its importance for the development of MIA methodology, land suitability analysis will also be presented. Impact assessment will be analysed in a different sub-section.

Cost-Benefit Analysis (CBA) was initially conceived to evaluate American federal projects on water resources, and the UK investments in transports. Later this methodology was extended to the appraisal of several kinds of public actions and projects. It is probably the evaluation method most widely used. The technique, although complex, uses one main criterion, the willingness-to-pay, and follows a simple principle – the association of a monetary value to each identified effect of a project or action. In order to determine if the benefits, or the desired effects of a project, are larger than the costs, or the undesired effects, a number of monetary classifications are summed up in a grand index.

The Planning Balance Sheet Analysis (PBSA) was presented by Lichfield in the 1950s and, soon after, applied by this author in a number of plans in Britain (Lichfield, 1956). It is an adaptation of CBA to urban and regional planning, sharing the basic theory and techniques of the former. PBSA goes beyond CBA in two aspects at least: it integrates non quantifiable impacts, introducing symbols in the appraisal tables alongside with monetary impacts; and it records detailed information on costs and benefits distinguishing how the different social groups and stakeholders will be affected by the proposed plan under analysis. More recently, Lichfield (1996) presented the Community

Impact Evaluation (CIE) – a natural departure from PBSA, with similar foundations on the CBA and on impact assessment.

Hill presented the Goals-Achievement Matrix (GAM) in his PhD thesis in 1966, as an attempt to eliminate the weaknesses of existing evaluation methods, particularly the CBA and the PBSA (see Hill, 1968 for a synthesis). This method has been used in the evaluation of urban plans in Great Britain. The main characteristics of GAM are the organization of effects according to the goals and to the different parties involved, and the incorporation of non-monetary effects in the grand index. The main stages of this method are: the definition of goals and objectives in operational terms to enable the measurement of their achievement; the attribution of value weights to the goals, reflecting their importance; the identification of goals achievement to different groups; the sum of achievement levels in a grand index; the adjustment of this index, considering equity issues.

Multi-criteria Analysis (MA) emerged in the 1960s in France. The *Electre-techniques* or *Concordance-techniques* soon became dominant among the new evaluation methodologies. In general, MA methods adopt the form of a matrix with at least two dimensions, one expressing the different project alternatives, and the other, the objectives and the evaluation criteria. The relative importance of the different criteria is reflected by an appropriate set of priorities or weights. As Lichfield's method is inseparable from CBA also contemporary MA is strongly related to GAM. For more information on these methods see Voogd (1983) and Nijkamp et al (1990).

Threshold Analysis (TA) was proposed by Malisz in Poland, in 1963, and further developed namely by Kozlowski – who introduced the method in the UK in 1965 – and Hughes (see for example Koslowski and Hughes, 1972; Malisz, 1963). It was generated by the need to develop effective cooperation between physical planners and economists, to help the dialogue between different planning levels, and to refine the (long-term) planning process. It is based on the assumption that cities encounter limitations to their development, due to topography, land uses and technology of infrastructure. These limitations, called development thresholds – which should be identified and measured by the proposed method – are irremediable and can be overcame only at additional costs, or threshold costs. The major contribution of TA lies in four main issues, enabling: an improved planning methodology, a measure of efficiency, a basis for improved interdisciplinary cooperation, and improved links with decision-making. As Kozlowski and Hughes (1972) stated, it remains a strong need to balance TA processes and results with other complementary studies covering together the comprehensive spectrum of the planning process.

McHarg's method of Land Suitability Analysis is synthesized in the book *Design with nature* (McHarg, 1969). The method is framed by an environmental philosophy, where man and nature should not be viewed separately, providing an expert judgment based on the scientific knowledge of natural environment. The application of the method is expressed by a map overlay. The ratings on each part of the territory under analysis are expressed in the form of shades of gray: the darker the shade, the less suitable the territory for the proposed land-use. A map of each land characteristic is prepared on clear plastic overlays, using the color shadings to indicate the variations in the characteristic throughout the study area. In the original applications of the method, the plastic sheets were placed one over the other and viewed with the assistance of a back-lighted map table. The composite picture that emerged was a pattern of light and dark shades indicating the estimated aggregate suitability of each land parcel in the study area for the particular land use. The optical process of adding shades was then expressed by a mathematical equation (McAllister, 1982). The introduction of GIS-based approaches to land-use suitability analysis (Malczewski, 2004) has enabled a wider range of applications, and the method became an integral component of, everyday, urban, regional and environmental planning activities.

3.1.2. Ex-post evaluation in planning

Planning evaluation methods focused on plan implementation and on the planning process are framed by the debate between conformance and performance. Conformance-based evaluation means judging the success of failure in planning efforts by one or both standards. One is the degree to which outcomes on the ground fit the plan or conform to planning prescriptions; the other is whether a plan or policy implementation instruments in fact promote the espoused planning objectives (Alexander, 2009). After the development of some fundamental research works in the end of the 1970s (Alterman and Hill, 1978; Calkins, 1979) and in the second half of the 1990s (Baer, 1997; Talen, 1996b, 1997), a number of interesting studies on this topic have been produced throughout the last decade, mainly in the United States – see Table 2.

Performance-based evaluation follows from defining a plan or policy as a decision framework. Its performance is an expression of its usefulness and effectiveness in filling this role: whether and how the subject plan or policy was consulted for subsequent decisions and was followed in implementing plans, programmes and projects (Alexander, 2009). Based on the work of Fudge and Barrett (1981), who have highlighted the differences between a performance and a conformance view, the Dutch school of planning evaluation has been developing a continuous research on performance.

In some few cases, studies on plan implementation explored the potentialities of an integrated use of both approaches (Alexander and Faludi, 1989; Oliveira and Pinho, 2009) and their simultaneous application for comparative purposes (Altes, 2006; Berke et al, 2006).

3.2 Urban form and urban development

Studies on urban form and urban development can be roughly divided accordingly to the level of analysis, at macro level (European or National) or at micro level (municipal or local). Although this paper makes some references to the former, it is mainly focused on the latter.

Research studies on urban development, urban form, and land use at a macro scale have been mainly promoted by the European Commission. CORINE (Coordination of Information on the Environment) complied and organized information on the state of the environment, including the land cover structure, in the Member States. MOLAND (Monitoring Land Use / Cover Dynamics) provided a spatial planning tool for assessing, monitoring and modelling the development of urban and regional environments. GEOLAND (Integrated GMES Project on Land Cover and Vegetation) provided a framework to develop and demonstrate a range of reliable, affordable and cost efficient European geo-information services. The URBAN AUDIT provided European urban statistics for 258 cities across 27 European countries. It contains almost 300 statistical indicators presenting information on demography, society, economy, environment, transport, information society and leisure. The DOBRIS ASSESSMENT covered the state of the environment in almost all of Europe's nearly 50 States, aiming at describing and explaining the changes and effects in the environment, and to provide a comprehensive picture of the state of Europe's environment.

During the last decades a number of studies and approaches on urban form at a lower scale have been developed. Comprehensive literature reviews or papers focusing on different approaches are rare (see for example Kropf, 2009; Osmond, 2010; Pinho and Oliveira, 2009). The next paragraphs briefly describe some leading approaches on the study of urban form: the Conzenian school, the Muratorian school, the normative approach, the space syntax, isovist analysis, cellular automata, agent-based modelling, shape grammars, and finally, fractal analysis.

The Conzenian school (Conzen, 1960; Larkham, 2006; Whitehand, 2007) has been mainly developed by the Urban Morphology Research Group / UMRG in the University of Birmingham after the seminal work of Conzen. This school approaches the urban form and structure for descriptive purposes, with the aim of developing a theory of city building. The focus is on how cities are built and why. It purposes a tripartite division of townscape in town plan (site, streets, plots and block plans of buildings), building fabric (three-dimensional form), and land use. The historical development is analysed according to concepts such as morphological period, fringe belt, morphological region, burgage cycle and morphological frame.

The Muratorian School (Muratori, 1959; Cannigia, 1963; Cataldi, 2009) approaches the urban form for prescriptive purposes, with the aim of developing a theory of city design resting on historical city-building traditions. The focus is on how cities should be built. As in the previous school this approach develops around a number of concepts such as type, fabric, organism, operative history, to name just a few.

The so-called Normative approach (Alexander, 1965; Alexander et al, 1977; Cullen, 1961; Krier, 1975; Lynch, 1960, 1981) is based on the analysis of successful case studies, and on the consequent selection of the principles that had contributed to that accomplishment. This approach aims at finding a practical connection between analysis and design. It is supported by a normative discourse, pointing out the definition of urban policies, conceptual solutions and evaluation tools.

Space syntax (Hillier, 1996; Hillier and Hanson, 1984) is based on a theory of space as an aspect of social life. It focuses on space, providing a representation of spatial relationships, expressed by a number of syntactic measures aiming at the establishment of a pattern language oriented approach. It holds a number of key concepts namely spatial configuration, axial map and axial line.

Methods such as axial analysis and segment analysis, or software applications (Depthmap, Confeego, Segmen, to name a few) have been used by a growing international community.

Besides space syntax some quantitative approaches have emerged in the last decades (for a synthesis see Batty, 2005). Isovist Analysis (Benedikt, 1979) involves measuring the geometric properties of the isovist field associated with particular environmental configurations. Cellular automata represent physical systems as cells within a grid, subject to transition rules which specify the cell's behaviour based on input from neighbouring cells. Agent Based Models / ABM, developed from artificial intelligence research, removed the need for reliance on cell-based rules. As autonomous, goal-directed software entities, agents carry out their pre-programmed instructions without further interference from the programmer (see for example Wu and Silva, 2010). Shape grammars (Stiny, 1980) constitute sets of rules for performing recursive operations – rotation, translation, combination, replacement – on an initial 2D or 3D shape, to obtain a set of alternative forms. Finally, Fractal Analysis (Mandelbrot, 1977; Batty and Longley, 1994) focus, obviously, on fractals, i.e. on a particular type of shape, with an irregular but self-similar form – the irregularities are repeated across many scales.

3.3 Impact assessment

Impact assessment can be generally understood as the process of identifying and evaluating the future effects or consequences of a current or proposed action. As such, it refers to an evaluation that precedes and supports the decision-making process of a new development (ex-ante evaluation – see section 2).

The concept of impact involves the comparison between the situation without the action/project and the situation with the action/project. Both cases should engage the characterization of the future evolution of the environment starting from the present state-of-art. The focus of analysis should be on those changes significantly affecting the environment. This means there must be some criteria to determine the impact significance (Canter & Canty, 1993), referring to, for example: the lack of conformity with pertinent laws or regulations, the characteristics of the location (protected areas, for example), the possibility of mitigation, the public concerns with impact risks and the existence of cumulative impacts or other related effects that can affect the prevision.

The term impact assessment is usually associated with the Environmental Impact Assessment (EIA) process, first proposed by the National Environmental Policy Act in 1969. Since then, the EIA process spread worldwide and has been introduced as a legal procedure in different countries. The methodology is sufficiently well-know and needs no further explanations (for more, see Canter, 1996; Glasson, et al., 1994; Jay et al., 2007). Other methodologies emerged, in the last decades, comprising other dimensions of the analysis, but preserving the main principles of the general framework. More specifically, we will refer the Social Impact Assessment, the Strategic Environmental Assessment, the Sustainability Appraisal and the Sustainability Assessment.

Despite being an evaluation methodology, EIA is usually recognized as the process of evaluating the likely impacts arising from a proposed project or development significantly affecting the environment. It is a process that has spread worldwide, with some differences in each context, but generally following the same general sequential procedure. This procedure ensures that the environmental effects of a development are identified and assessed before decision is taken assuring that the public takes part in the process.

The need for better understanding the social impacts in the EIA process of projects and policies, led a group of social experts to establish the International Committee on Guidelines Principles for Social Impact Assessment (ICGPSIA), with the purpose of defining a set of guidelines and principles that should assist the authorities and stakeholders involved in the EIA process. The main purpose of a SIA methodology is to assess the impacts on society of certain projects and planned interventions (Vanclay, 2006). The focus of SIA is the evaluation of intended and unintended social consequences of planned interventions and any social change processes invoked by those interventions (Vanclay, 2003). Nowadays, most socio-economic concerns are already incorporated, although playing a minor role, in other current formal planning and approval processes in several countries, in order to categorize and assess how major developments may affect populations, groups, and settlements. The SIA methodology follows a sequential framework, similar to the one of the EIA (for more, see ICGPSIA, 1994).

The main purpose of a Strategic Environmental Assessment (SEA) is to guarantee that the environmental effects of policies, programmes and plans are identified and assessed in the preparation phase, before they are adopted. The SEA differentiates from EIA basically on the nature of the object of analysis, giving the SEA a whole strategic approach, in contrast with EIA that focuses on the project level. In the case of the SEA, the spatial macro scale of analysis (global, national and regional) and the longer time scale (at long and medium term) contribute to a less rigorous assessment, and to a more distant and vague perception of the impacts. However, the strategic nature of the assessment allows more easily to the consideration of sustainability issues and a better consideration of cumulative effects. As Sheperd & Ortolano (1996) refer, the SEA has emerged in response to the urge need of integrating urban sustainability in EIA and comprehensive planning. Policies, programmes and plans can be evaluated according to environmental objectives and targets, and sustainability strategies can be part of this integrated framework. The SEA allows for a more proactive approach towards sustainable development in opposition to the EIA that is usually associated to the reactive approach at a project level.

Sustainability Assessment (SA) is a relatively recent concept that has been evolving due to the recognition of its importance as an evaluation tool to achieve sustainability. The term, however, is too generic, including a broad range of approaches (Pope *et al.*, 2004), emerging originally from EIA and SEA, and the recognition that those environmental processes should incorporate sustainability-based criteria. In the sustainability assessment, the focus shifts from minimizing damage (i.e., reducing the negative) to maximizing long term gains and opportunities for multiple parties. Although the EU argues that one of the SEA Directive aims is to achieve sustainable development, it would not be appropriate to say that the goals of a sustainability assessment are similar to those of the SEA or even EIA.

Some methodologies associated to sustainability assessment have recently emerged. One example is the process of sustainability appraisal that exists in some countries, such as the UK, in which social, economic and environmental considerations are integrated into plan revisions. Besides the term sustainability appraisal, other terms have appeared in the literature being also examples of either an EIA-driven integrated assessment or objectives-led SEA approaches, as referred by Pope, *et al*. (2004). That is the case of integrated assessment appraisal (discussed by Eggenberger & Partidário, 2000), or integrated impact assessment (Sheate *et al*., 2003) or even sustainability assessment (Lee, 2002, in Pope, *et al*., 2004).

The EIA-driven integrated assessment and the objectives-led SEA approaches represent, according to Pope, *et al*. (2004), the two possible approaches to sustainability assessment. The first is defined as being reactive because usually is the response to a proposal already conceived. The scope of analysis is not only limited to environmental impacts, but also to the social and economic dimension, embracing the three pillars of the sustainability concept. The final target is to minimize the adverse effects, maximizing the beneficial impacts. The objectives-led integrated assessment envisages the integration of environmental, social and economic objectives. The difference between the two is that the first ensures that impacts of the proposal are acceptable in comparison to the baseline conditions, and the second assesses to what extent the objectives that will be implemented can contribute to the sustainability principles.

3.4 Environmental accounting and energy related methods

In this section two groups of methods will be presented. A first group, designated by Environmental Accounting Methods (EAMs), gathers methodologies that analyze the stocks and flows of materials: Material Flows Analysis (MFA), Life Cycle Analysis (LCA), Material impact per unit of service (MIPS), Ecological Footprints (EF) and Sustainable Process Index (SPI). The second group relates to the analysis of energy in the urban system and considers the Emergy and the Exergy Evaluations.

In general, these methodologies are based on the input-output theory in economics, transferred as an analogy to the environmental impact analysis. The environmental resources are the inputs, and the purpose of the analysis is to maximize the output, when minimizing the environmental resources, in order to promote economic development with less environmental damages. Thus, as referred by Wang & Xu (2009) the environmental performance represents the environmental cost incurred by the economic development of modern societies, and the urban metabolism is surely a useful method to better estimate that environmental performance.

Material Flow Analysis (MFA) is a method from industrial ecology that systematically assesses the flows and stocks of materials within a given system defined in space and time. The method evolved from earlier concepts of material and energy balancing, from the work of Ayres in 1978. The first studies on the national level were presented at the beginning of the 1990s for Austria, by Steurer, and Japan, by the Environment Agency of Japan (Hinterberger, *et al*., 2003). From literature review, MFA is usually divided in three types of methodologies according to the object of analysis: i) the material flow accounting, when it is applied at a national or regional scale, focusing on the exchanges between economy and natural environment; ii) the corporate material flow analysis, or industrial supply chain, when it is applied to a company, studying the processes of production in order to obtain the most efficient ones regarding energy and materials; and finally, iii) the life cycle of a product or life cycle assessment, when it is applied to a product.

There are two possible approaches to the material flow accounting depending on the different levels of economic activity (Blanc, *et al*., 2009). At the macro level, the Economy-wide MFAs are presented at national and regional level, and the material inputs considered are domestic extraction and imported materials. At the meso level, the Input-Output Tables (PIOTs) are the most comprehensive type of accounts, including the material flows between production branches and the flows from production to domestic final demand.

MFA uses an Input-Output methodology applied to physical stocks and flows of economic systems. It consists of an accounting system that balances the inputs (such as extractions and imports) and outputs (such as consumptions, exports and wastes). It can be a supportive tool for decision-making in resource management, waste management and environmental management. The main limitations relate to the difficulties inherent to obtaining all the necessary data and to the need of conciliating methodologies applied in the different case studies in order to make them comparable.

As referred to before, Life Cycle Assessment follows a similar rationale as the one of MFA at the product level. The life cycle can be understood as the consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal (ISO, 2006). In the LCA, the aim is to determine and account for the effects – environmental and social damages that a product can provoke – and to select the least burdensome one. However, it should be noted that LCA accounts for the technology used in delivering the products and services, but does not evaluate the global impact associated to the production process and the economic choice for using it.

The Material Input Per Unit of Service (MIPS) is not as detailed as the LCA and can be considered mainly a screening method. The MIPS is a concept that was originally developed by Friedrich Schmidt-Bleek in Germany in the 1990s. The concept can be used to measure the eco-efficiency of a product or service and can be applied either to a single product or to more complex systems. The method calculates the materials required to produce a product or service. The rationale behind the MIPS concept follows the material flows analysis giving a good indication of the environmental risks and impacts of the human activities, including for example the emissions and wastes that originate pollution (Osmond, 2008).

The term Ecological Footprint (EF) first appeared in 1992, and was introduced by William Rees (Wackernagel & Rees, 1995). The concept is based on the assumption that anything that consumes resources/materials or energy needs a certain amount of land, water and other natural resources. The total footprint of a certain population's activities is quantified in terms of global hectares. It compares actual throughput of renewable resources relative to what is annually renewed. The methodology consists of a simple but detailed procedure. The EF assembles data from different sources: built-up land, consumption of crops, pasture, forestry and energy to derive land area equivalents (Blanc, *et al.*, 2009). It has been recognized that the EF is a useful and suggestive indicator to communicate to policy makers and to a wider public (Blanc, *et al*., 2009), and this is one of the reasons for its widespread application at national, regional or local level. It is also a valuable tool for comparison among different regions or countries.

The Sustainable Process Index (SPI) was introduced in 1996 by Krotschek and Narodoslawsky, and defines a similar method to the ecological footprint, focusing on the production of certain goods and services. The index reflects the area of land required to provide raw materials, energy, plant and equipment and waste disposal relating to the production process that is then divided by the area per inhabitant for the region associated to the production process (Osmond, 2008). Despite its more specific focus, with more rigorous sustainability valuation, the SPI is still subject to criticisms as the environmental impacts must be evaluated through a single index, and there is no room for maneuver in comparison to other cases with more accuracy.

Finally, there are two relevant energy related methods: Emergy and Exergy evaluations. The theory on Emergy was first proposed by Odum, in the 1980s, as a method for integrating the accountability for the quality of matter, energy and information within systems (Siche, *et al*., 2009). Emergy, spelled with an "m", measures both the work of nature and that of humans in generating products and services (Odum, 1996). The concept takes into consideration every contribution from nature and human economy in order to know the relative importance of each resource. Emergy therefore accounts for quality differences among distinct forms of energy and allows for the inclusion of information and monetary flows to those of energy and materials (Meillaud et al., 2005).

Exergy is a measure of the maximum amount of work which can theoretically be obtained by bringing a resource (energy or material) into equilibrium with its surroundings through a reversible process (Brunner & Rechberger, 2004). It is the fraction of complementary energy corresponding to entropy, i.e. the energy that keeps the capacity to be transformed into work. The Second Law of Thermodynamics requires that on irreversible transformations the exergy always decreases - an increase of entropy corresponds to degradation of energy through its dissipation as heat; this is inevitably a decrease of exergy. Recently, some studies have been published on the relation between exergy and environment. Reduction of environmental impact, increasing efficiencies of resources utilization, sustainable energy use, land use and urban planning are best addressed by using an exergy evaluation method.

3.5 The Urban Metabolism

The concept of urban metabolism was developed in the industrial ecology field and originally introduced by Abel Wolman in 1965 to determine the urban metabolism of a typical American city. This concept compares a city to a living organism, in order to better understand the functioning of urban areas. The analysis comprises the quantification of the flows of energy, water, materials and wastes into and out of an urban region. Following Wolman's work, other metabolism studies have been conducted to cities worldwide. These studies, from industrial ecology and urban ecology, make evidence the importance of particular aspects (such as urban form, material supplies, infrastructures networks supplies, or groundwater withdrawals) in the calculation of the overall urban metabolism.

Recently, the interest for urban metabolism has increased due to the recognition that the model can provide a more comprehensive understanding of the sustainability of a city. First, the model gives a holistic and integrated viewpoint of an urban region. Second, it is able to examine aspects of urban relationships among infrastructures and inhabitants, beyond the strictly functional analysis of urban systems. By comprising the analysis of all activities in an integrated and cyclical approach, urban metabolism can offer a way of measuring urban sustainability within the ecosystems capacity to support it. Additionally, there is a need to view the urban system as a whole if the aim is to understand and solve complex urban problems.

A definition of urban metabolism is given by Kennedy, *et al*. (2007) as 'the total sum of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste'. Thus, the economy is basically interconnected with the surrounding environment through the material and energy flows. The impact on the environment, or the size of the metabolic throughput, can be then estimated by the amount of materials that society appropriate from the environment and return back to it in other forms (EC, 2001).

One of the main difficulties associated with the urban metabolism model relates to obtaining the adequate data for the total amounts of stocks and flows. It is usually very complicated to assemble all types of materials produced or consumed in an urban area, or even the amount of energy flows, for example. Throughout the last decades, different studies have been trying to develop new ways of integrating the maximum of data as possible, although most of them have only developed a partial analysis of the urban areas. It is evident from the literature, that urban metabolism usually considers five different flows or cycles of the environment: water, materials, soil, nutrients and energy (Kennedy *et al.*, 2007).

4 The Metabolic Impact Analysis

4.1 Introduction to MIA

This section presents the general features of a novel methodology, the Metabolic Impact Analysis (MIA). This methodology provides an operational instrument to assess the overall impact of a particular development proposal on the existing urban metabolism performance of a given city, metropolis or city region.

MIA attempts to address a common problem found in many cities throughout Europe and elsewhere. Often times, a particular development project or urban project seen in isolation, i.e. detached from the geographical context in which it will be located, may well look quite attractive and able to secure, in principle, a sustainable performance from an energy, water, materials and land, point of view. However, when plugged into the existing and receiving urban fabric, the final overall results may well fall short of the most reasonable and substantiated expectations and instead of improving the overall urban metabolism performance of the city it may well end up contributing to worsen that same performance. The other way around may also be true. A given development proposal may not be, in isolation, that interesting from an urban metabolism perspective and yet, in the right location, it could provide a positive contribution to the overall metabolic performance of a particular city.

4.2 Main influences of MIA

The following are the main sources of inspiration that assisted the general conceptualisation of MIA. To start with, MIA draws on EIA methodologies. Both are geared towards tackling new proposals and both attempt to provide an operational tool for analysis and assessment. However, while in EIA the environment is seen as a sum of different and to some extent isolated components, from air, water and solid wastes, to noise and vibration, landscape quality or socio-economic factors, MIA provides an embracing and holistic perspective based on the urban metabolism concept (see Table 3). In fact, it has some resemblances to the Sustainability Assessment approach referred to before in which the sustainability concept offers the glue to integrate the different analysis topics.

MIA has also been influenced by the somehow démodé Threshold Analysis of the Polish planning researcher Malisz, back in the 1960s. The idea of selecting directions for expansion areas, in a particular city, in accordance to cost minimizing solutions as far as the existing provision of infrastructures and public equipments are concerned has some obvious similarities to MIA. MIA is able to explore the installed urban metabolism capacities and natural capital across the complex puzzle of urban fabrics that constitute the contemporary city.

MIA has also been influenced by Ian McHarg’s Design with Nature (1969) in respect to the systematic use of layers of environmental information and to the application of the environmental sensitivity concept. Contrary to the mainstream application of the urban metabolism concept that simply ignores the spatial dimension of development processes and of the sustainability concept, MIA explores this spatial dimension and attempts to take the best use of GIS techniques. See Table 4 for a synthesis of these influences.

In addition, the urban metabolism and the environmental accounting methods made evident some relevant and useful aspects on the design of MIA. The first refers to the importance of defining the system boundaries. All these methods follow the same common rationale of what can be called a *black box*, and the accountability of the inputs and outputs of a certain system. Secondly, the environment is modeled according to a system and/or sub-systems. The components of the environment are understood in an integrated and holistic way within those sub-systems. An urban metabolism perspective of analysis will allow, in this way, for a more integrated analysis of the impacts of a proposed intervention within the systems boundaries, in contrast to the impact assessment methodologies. Finally, the last aspect refers to the difficulties in obtaining data/information for the system and the planning proposal, and recognizing that available data is usually presented in annual terms, but not always for the adequate scale of analysis, matching the system boundary. This limitation will require some adjustments in practical applications of MIA.

4.3. Fundamental principles of MIA

The following are MIA's general purposes. First, it evaluates the urban development process, from a metabolic perspective. The urban metabolism concept was initially developed for large territorial units – countries, regions, metropolis and large cities. At city level, the application of urban metabolic models tends to embrace the whole city territory as a black box. MIA uses this same concept, however, it is geared not only to the assessment of overall city development scenarios but also, and more importantly, towards the assessment of urban transformations within the city.

Second, MIA focuses on plans and projects as fundamental drivers of the urban development process. The evolution of our cities and metropolis is shaped by numerous and successive public and private investment decisions - these decisions are framed by the local planning system in operation. Land use plans, urban development projects and, also, urban policy documents are the main objects of analysis of MIA.

Third, the methodology assesses the city wide metabolic impact of the proposals included in plans and projects. The likely changes in the overall metabolic performance of a city derived from the implementation of urban plans and projects constitute the main output and, indeed, the main contribution of MIA.

Fourth, MIA explores the spatial dimension of alternative development processes, by focusing on particular plans and projects with specific and, sometimes, alternative locations within cities. MIA attempts to explore the hidden territorial dimension of the urban metabolism concept. Needless to say that, this territorial dimension is essential for planning purposes.

Fifth, it may address different temporal scales but is better suited to short-term assessments. MIA can be applied to long and medium term assessments. However, due to the complexity and to the ever-changing relationships between urban metabolism variables, the application of MIA to short-term (ex-ante or ex-post) analysis will surely provide far more accurate results. Similarly to Input-Output techniques, MIA is tailored to either explore the near future or assess the recent past. In fact, MIA relies on existing urban metabolism models that are continuously changing reflecting the rapid transformations in the working of our cities and metropolis.

Sixth, it deals with the environment in an integrated way. Through the systematic analysis of the changes in, and interactions between, stocks and flows of energy, water, materials, and land, the rationale behind the urban metabolism concept offers the necessary tools to understand and integrate the complex web of interdependencies between the natural and the built environments.

4.4 MIA evaluation process

The application of MIA in a given city requires the previous availability of an overall urban metabolic model, sufficiently updated to provide an accurate picture of the most important metabolic processes, covering the energy, water, material and land matrices. A comprehensive GIS database including land use, natural and built environment, as well as transport variables is also needed.

The evaluation process associated to MIA comprises six main stages as follows (see Table 5). The first stage corresponds to the definition of the study area, scoping and the intervention area. Within the larger city or metropolis – the study area for which a metabolic model is previously available – a confined intervention area has to be defined to initiate the MIA application. Generally speaking, the intervention area is defined according to the nature of the evaluation object, i.e. the planning proposal, the urban plan or the urban project one intends to analyze, as well as the scope of the analysis in terms of energy, water, materials and land. The intervention area has not a single and precise definition; it has a "variable" geometry according to the metabolic dimension under analysis. For instance, the energy dimension of the metabolic impact analysis may well require a different boundary from the water dimension, the land dimension or the materials dimension. That is why a simple scoping exercise is necessary at this stage, selecting the components of urban metabolism that should be analyzed are identified according to the nature of the project.

The intervention area should correspond to the smallest area able to analyze the direct interactions of the planning proposal with the rest of the city. On the contrary, the study area is the area of the city that supports the application of the general (and previously available) urban metabolic model. If the proposal encompasses alternative locations the corresponding intervention areas have to come on board. This option will enhance all the exercise, in particular the final stages of the assessment process.

The second stage of the evaluation process involves the metabolic characterization of the study area. A baseline characterization of the study area, from a metabolic point of view, is needed. This characterization shall take advantage of the city's urban metabolism model to describe the main city inputs, throughputs and outputs, in terms of flows and stocks of energy, water, materials and land. Let's call it submodel 2. The metabolic role and performance of the city can be explored and diagnosed. The main metabolic issues affecting the city (the study area) shall become explicit.

The third stage corresponds to the metabolic characterization of the planning proposal. The planning proposal – the object of analysis – shall also be characterized from a metabolic perspective and on the basis of the intervention area previously defined. A description of the likely inputs, throughputs and outputs associated to the planning proposal, in terms of flows and stocks of energy, water, materials and land have to be estimated (submodel 3). This description should be able to match, at least in part, the main metabolic issues revealed by the city (study area) characterization (Stage 2).

The fourth stage involves the identification and characterization of the metabolic impacts. In order to identify and characterize the metabolic impacts of the planning proposal under analysis, the two sub models developed in stages 2, study area, and 3, planning proposal (intervention area) have to come together, plugging in the proposal to the larger territory of the city on which it will be located. This exercise is expected to reveal the overall forecasted inputs, throughputs and outputs associated to the implementation of the object, not just on the intervention area but also, and most importantly, on the entire urban metabolism of the city or metropolitan area (the study area). It will highlight the net potential contribution of the plan (or project), in other words, the added value of the proposal to the global urban metabolic performance of the city.

The fifth stage is the evaluation of the proposal and alternative scenarios. The net metabolic impact of the proposal and/or alternatives, positive or negative, have now to be considered in a wider perspective of the general dynamics and transformation goals previously set for the city. This stage will address issues related to public and institutional participation, overall understanding of urban development processes, interplay between development actors, to name just a few.

Finally, the sixth stage of the evaluation procedure corresponds to potentiating the metabolic efficiency**.** MIA was designed not just to support decision making (Stage 5) but also to provide a sound basis for the improvement of development proposals, as far as their metabolic performance is concerned. In this respect the final results of the application of MIA are bound to illustrate ways to improve the intrinsic quality of the proposals as well as the way they fit and adjust to the urban context they are supposed to address. In other words, these final results are likely to incorporate a number of recommendations to change and/or adapt the development proposals, plans or urban projects to the particular circumstances of the city or metropolitan area, in order to improve the metabolic performance of both the proposal and the city at large.

5 Conclusions and further research

This paper has two main goals: a selection and a brief presentation of the most important evaluation methodologies from an environmental planning and an urban metabolism point of view; and the development of an innovative methodology based on the urban metabolism concept and designed to assess specific planning proposals.

Under the first objective, a set of approaches and methodologies were outlined grouped under five main fields: planning, urban form, impact assessment, environmental accounting and energy related methods, and urban metabolism. Malisz's threshold analysis, McHarg's land suitability analysis, and the environmental impact assessment were highlighted as the main influences of MIA. Under the second objective, the MIA was presented and justified, considering the links with other evaluation methodologies, the possible field of application, and the main methodological steps.

Our further research will involve a practical application of MIA taking the city of Oporto as a truly testbed for this methodology. As a result, the present format of MIA is likely to suffer some adjustments and improvements provided by the insights and lessons learned from a real first application. Subsequently, three other applications of MIA will be carried out in 2010 to the cities of Vienna, Stockholm and Newcastle-upon-Tyne.

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Table 1. Methods of evaluation (ex-ante)

1.	Checlist of criteria
2.	Quality of service
3.	Norms and standards
4.	Goals/objectives
5.	Linear programming
6.	Impact assessment (fiscal/financial; environmental; social)
7.	Urban/community impact
8.	Multi-attribute
9.	Multi-criteria
10.	Multi-criteria decision-making
11.	Unit Costs
12.	Threshold analysis
13.	Costs in use
14.	Financial analysis
15.	Social financial analysis
16.	Cost revenue analysis
17.	Planning and programme budgeting
18.	Cost-benefit analysis (single objective; cost effectiveness; cost-minimization)
19.	Social cost-benefit analysis (multiple objective)
20.	Framework appraisal / assessment summary
21.	Optimization
22.	Cost-benefit matrix
23.	Planning balance sheet analysis
24.	Community impact analysis
25.	Social audit

Source: Lichfield (1996)

Table 2. Methods of evaluation (ex-post)

Conformance-based approaches	Performance-based approaches
Alterman and Hill (1978) Implementation of urban land use plans	Damme et al (1997) Improving the performance of local land-use plans
Calkins (1979) The planning monitor	Driessen (1997) Implementing situations in rural land development
Talen (1996a) Methods to evaluate the implementation success of plans	Lange et al (1997) Performance of national policies
Baer (1997) General plan evaluation criteria	Mastop (1997) Performance in Dutch spatial planning
Burby (2003) Citizen involvement and government action	Mastop and Faludi (1997) Evaluation of strategic plans: the performance principle
Laurian et al (2004b) Evaluating plan implementation	Mastop and Needham (1997) Performance studies in spatial planning: the state of the art
Brody and Highfield (2005) Testing the implementation of local environmental planning	Needham et al (1997) Strategies for improving the performance of planning
Brody et al (2006) Measuring the adoption of local sprawl reduction policies	Faludi (2000) The performance of spatial planning
Chapin et al (2008) A parcel-based method for evaluating conformance	Faludi (2006) Evaluating plans: the application of the ESDP

Source: Oliveira and Pinho (2010)

Table 3 - Differences between MIA and EIA.

MIA	EIA
The study area is not defined by total intervention area of the urban project under analysis, instead coincides with the city or metropolis boundaries for which the urban metabolic model is available	The geographical scale of the study area tends to be predefined by the characteristics of the project under analysis and may very slightly in accordance to the environmental component under consideration (watershed, airshed, etc)
Application to specific Plans and Projects. It can also be applied to Policies and Programmes, however this application will be more complex and demanding	EIA – Projects SEA - Policies, Programmes, Plans
The environment is dealt with in an integrated way (notion of metabolism)	The environment tends to be artificially fragmented into several components
The evaluation rationale is provided by the city or metropolis territory	The evaluation is structured around the object of assessment
Evaluation can be ex-ante and ex-post and is better suited to short-term analysis	Evaluation can adopt longer time frameworks but is essentially an ex-ante exercise
It is unlikely to ever have a specific legal or regulatory support, but it can be informally articulated with the planning process	Has a specific legal basis and is usually integrated in the development control process (according to specific screening procedures)

Table 4. The main influences of MIA

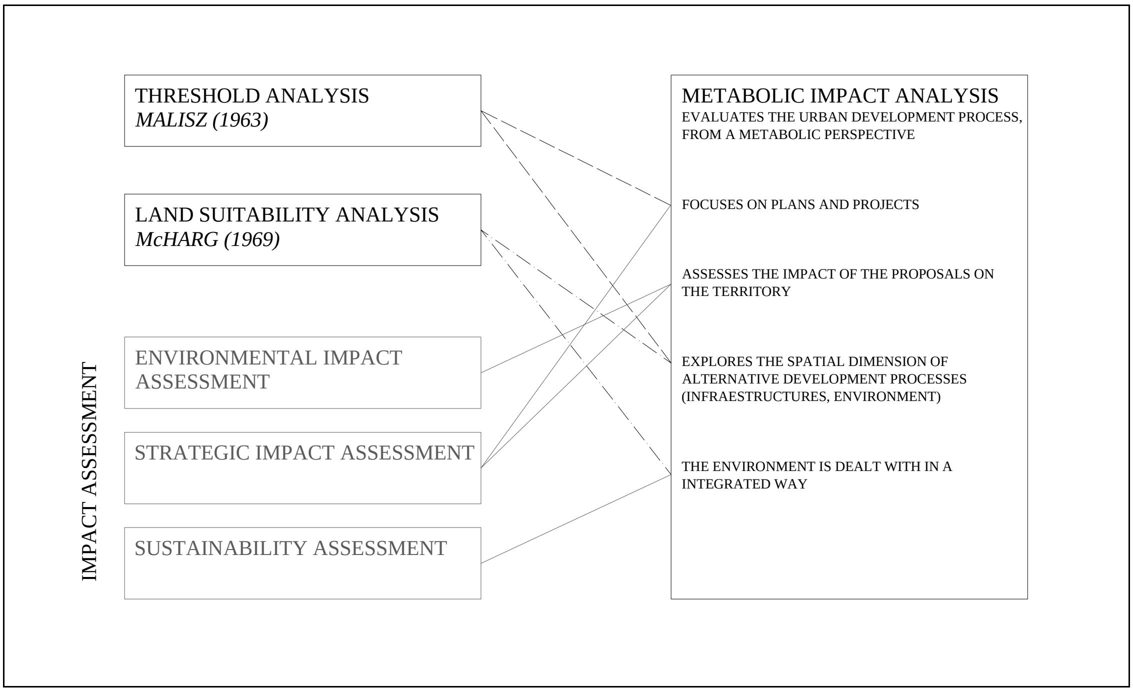

Table 5. General framework of MIA