Multidisciplinary Loop for Urban Sustainability

Bucle multidisciplinar para la sustentabilidad urbana

Circuito multidisciplinar para a sustentabilidade urbana

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Molina-Prieto, L., Suárez-Serrano, M., & Villa-Camacho, M. (2019). Multidisciplinary Loop for Urban Sustainability. *Revista de Arquitectura (Bogotá), 21*(2), 76-88. doi: http://dx.doi.org/10.14718/RevArq.2019.21.2.2048

http://dx.doi.org/10.14718/RevArq.2019.21.2.2048

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Abstract

Accelerated growth of the urban population creates environmental, economic, and social problems, in which inputs require urban processes for their normal functioning (energy, materials, and water), in industrial, economic, and human aspects. Additionally, the outputs generated in the production of goods and services are recognized, which create a series of undesired externalities. The methodology included interdisciplinary work, divided into four phases: planning, literature review, interpretation of the results, and formulation. As a result, we present eight concepts that strengthen urban sustainability: closed loop, urban metabolism, industrial ecology, circular economy, value network, inverse logistics, environmental psychology, and eco-design, upon which a proposal to strengthen urban sustainability through a multifactorial model was created. The article concludes that to achieve urban sustainability, it is necessary to create connecting vessels between disciplines that directly affect the dynamics that give life to contemporary cities.

Keywords: Resilient cities; inclusive development; sustainable urban development; urban environmental management; urban planning; environmental psychology.

Resumen

El crecimiento acelerado de la población urbana genera problemas ambientales, económicos y sociales en los que se reconocen los *inputs* que requieren los procesos urbanos para su normal funcionamiento (energía, materiales y agua) en aspectos industriales, económicos y humanos. Asimismo, se identifican los *outputs* generados en la producción de bienes o servicios, los cuales originan una serie de externalidades no deseadas. La metodología contó con un trabajo interdisciplinar organizado en cuatro momentos: planeación, revisión bibliográfica, interpretación de los resultados y formulación. Como resultado se presentan ocho conceptos que fortalecen la sustentabilidad urbana: ciclo cerrado, metabolismo urbano, economía circular, ecología industrial, red de valor, logística inversa, psicología ambiental y ecodiseño, a partir de los cuales se generó la propuesta de un modelo multifactorial para el fortalecimiento de la sustentabilidad urbana. Se concluye que para alcanzar la sustentabilidad urbana urge crear vasos comunicantes entre las disciplinas que inciden de manera directa en las dinámicas que dan vida a las ciudades contemporáneas.

Palabras clave: ciudades resilientes; desarrollo inclusivo; desarrollo urbano sustentable; gestión ambiental urbana; planificación urbana; psicología ambiental.

Resumo

O crescimento acelerado da população urbana gera problemas ambientais, econômicos e sociais nos quais são reconhecidos os inputs que requerem os processos urbanos para seu normal funcionamento (energia, materiais e água) em aspectos industriais, econômicos e humanos. Além disso, são identificados os outputs gerados na produção de bens ou serviços, os quais originam externalidades não desejadas. A metodologia contou com um trabalho interdisciplinar organizado em quatro momentos: planejamento, revisão bibliográfica, interpretação dos resultados e formulação da proposta do circuito multidisciplinar. Como resultado, são apresentados oito conceitos que fortalecem a sustentabilidade urbana: ciclo fechado, metabolismo urbano, economia circular, ecologia industrial, rede de valor, logística reversa, psicologia ambiental e ecodesenho, a partir dos quais foi gerada a proposta de um modelo multifatorial para fortalecer a sustentabilidade urbana. Conclui-se que, para atingir a sustentabilidade urbana, é urgente criar vínculos entre as disciplinas que afetam, de maneira direta, as dinâmicas que dão vida às cidades contemporâneas.

Palavras-chave: cidades resilientes; desenvolvimento inclusivo; desenvolvimento urbano sustentável; gestão ambiental urbana; planejamento urbano; psicologia ambiental.

Received: abril 10 / 2018 Evaluated: septiembre 11 / 2018 Accepted: mayo 27 / 2019

E-ISSN: 2357-626X
ISSN: 1657-0308

Introduction

This article pertains to the results of the research project, "Design of a closed loop value network for the manufacturing industry of Bogotá," which was endorsed and funded by the Fundación Universidad de América and conducted within the framework of three research groups at said university: "Territory and Habitability ," "Logistics " and "Organization Management and Competitiveness ." The project took place from January to December 2018. Based on a multifactorial model whose objective is to strengthen urban sustainability, the project also led to the concept presented here: a Multidisciplinary Loop for Urban Sustainability.

The accelerated growth of urban populations worldwide has generated serious environmental, economic and social problems. The environmental problems include: degradation of ecosystems and loss of biodiversity due to contamination from urban waste, negative impacts on human health, the production of greenhouse gases, accelerated climate change and its repercussions (Fernández, 2011). The economic problems include: an increase in urban poverty, higher rates of unemployment, low levels of education, higher crime rates, and a climate of fear (Rucks-Ahidiana and Harding, 2015). The social problems include: exclusion, segregation, marginalization, urban fragmentation, inequality, and polarization (Musterd and Ostendorf, 2013).

In 2017, the world population reached 6.6 billion inhabitants, and by 2030 it is expected to exceed 8.5 billion (United Nations, 2017). In 2014, globally, 54 of the population lived in cities. This measurement varied by region: 82% in North America, 80% in Latin America, 73% in Europe, 48% in Asia, and 40 % in Africa (United Nations, 2014). With respect to Colombia, the World Bank reported that 77% of the population lived in urban centers in 201

Inputs

The standard functions of a city require huge amounts of energy, raw materials and water, and these resources are mostly finite. Energy is necessary for transportation, industry, commerce, construction, infrastructure, water distribution and food production. Globally, cities consume 75% of the total energy generated (UN-Habitat, 2012), but each city requires a different amount of energy depending on characteristics such as scale, area, population and level of development. This energy is consumed in variable proportion by three main urban sectors: construction, industry and transport (Table 1).

City	Year	Energy Consumed			
		Residential	Industry and Commerce	Transportation	Total
Philadelphia	2015	51.582.023	69.860.346	28.098.920	**149.541.289**
Las Vegas	2014	23.130.376	64.842.663	93.025.588	**180.998.626**
New York	2014	363.383.312	460.081.837	136.109.809	**959.574.958**
Washington D.C.	2013	17.263.134	48.698.452	22.710.208	**88.671.793**

Table 1. Energy consumed in four US cities (in MMBtu*)

Source: Prepared by the authors based on the American Council for an Energy-Efficient Economy (ACEEE) (2017).

*MMBtu = one million Btu; Btu = British Thermal Unit.

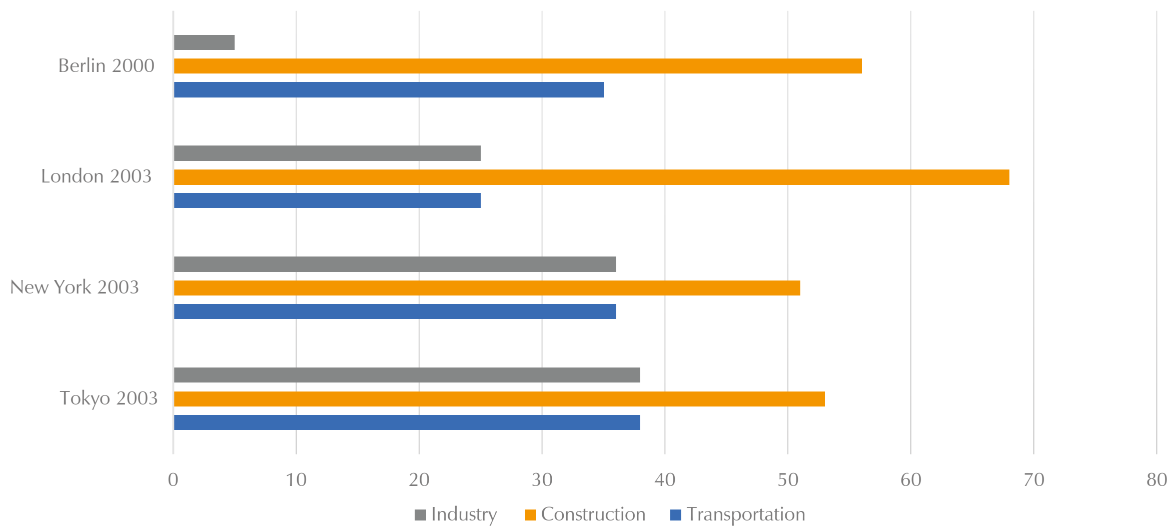

Figure 1. Energy consumed by four cities in developed nations (by %)

Source: Prepared by the authors based on United Nations (2008).

Este artículo está disponible en español en la página web de la *Revista de Arquitectura (Bogotá)*
http://dx.doi.org/10.14718/RevArq.2019.21.2.2048
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Figure 2. Energy consumed by four cities in nations with intermediate incomes (by %)

Source: Prepared by the authors based on United Nations (2008).

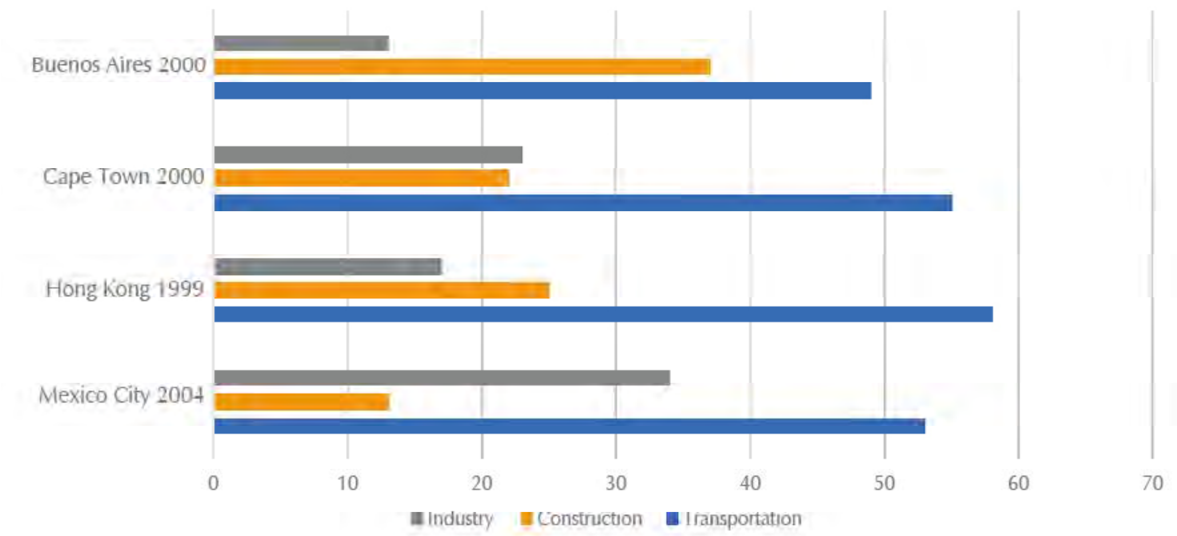
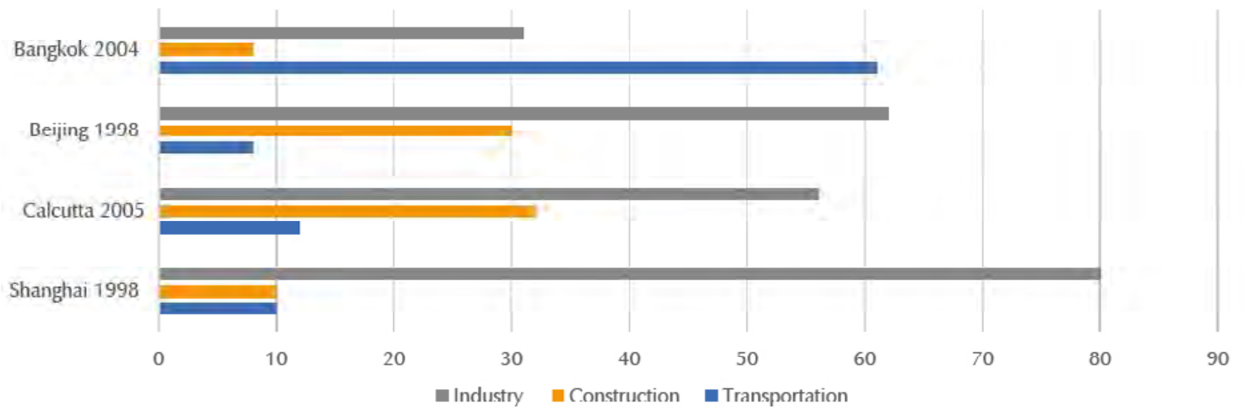


Figure 3. Energy Consumed by three megacities in Asia (by %)

Source: Prepared by the authors based on United Nations (2008).



In cities in developed countries, more than half of the energy is consumed by the operation and maintenance of the built infrastructure, about 30% by the transportation system and the rest is consumed by industry (Figure 1). Bogotá, the capital of a developing country, consumed a total of 183,715,392 MMBtu in 2010, slightly more than the energy consumed by Las Vegas in 2014 (Alfonso and Pardo, 2014).

In cities from intermediate economies, more than half the energy is consumed by transportation, the rest is distributed in varied proportion between construction and industry (Figure 2).

In the megacities of developing nations, like China or India, industry consumes up to 80% of the energy (Figure 3).

On the other hand, the main materials that cities require are: biomass for the provision of food and for the production of some organic items; fossil fuels—coal, oil and natural gas—to generate energy; metallic and non-metallic minerals for industry; and materials for the construction industry: sand, stone, clay and cement supplies (Schaffartzik et al., 2014).

Agrarian societies mainly consumed organic materials (biomass) for food, firewood and shelter (Franke, Busch and Zeitz, n.d.). With the evolution of civilizations, not only has there been a change in the materials that cities require, but demand has multiplied as well. The global transition from agrarian societies to industrialized regimes is linked to the massive exploitation of natural resources, such that the human race currently uses approximately 68 gigatons[1] (GT) of materials per year—ten times more than one hundred years ago (Schaffartzik et al., 2014). In the last seventy years, the extraction of materials for cities has grown at an exponential rate, especially in Asia and Latin America (Figure 4). With respect to Bogotá, in 2010, a total of 2.9 billion tons of biomass (food) and 6 million tons of construction materials were consumed in the city (Alfonso and Pardo, 2014).

Regarding annual water use, New York stands out globally with 10.9 million megaliters[2] (ML) followed by Guangzhou with 9.8 million, Shanghai with 7.5 million, Los Angeles with 6.6 million, Tokyo with 4 million, Mumbai with 3.9 million, Mexico City with 3 million, Beijing with 2.9 million, Seoul with 2.7 million, Osaka with 2.5 million, Buenos Aires with 2.2 million, Cairo with 2.1 million, and São Paulo with 2.1 million. The rest of the cities in the world each consume less than 2 million ML per year (Kennedy et al., 2015). According to officials from the Bogotá Aqueduct and Sewer Company, an effective net

1 One gigaton = one billion tons.

2 One megaliter (ML) = one million liters of water.

E-ISSN: 2357-626X
ISSN: 1657-0308

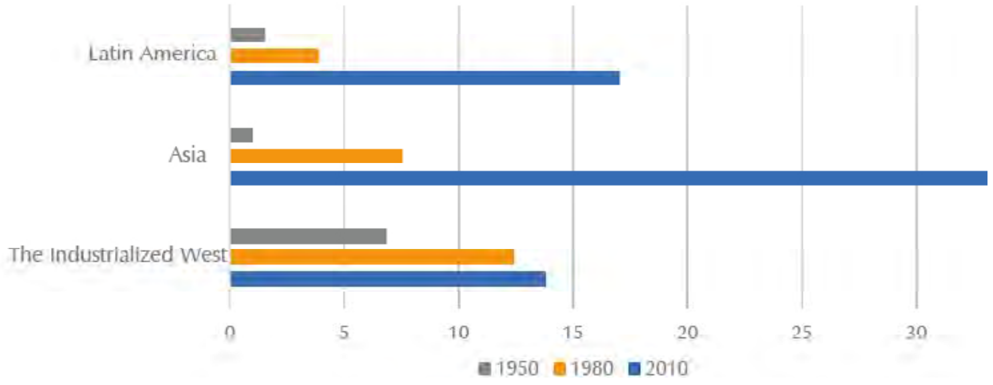


Figure 4. Consumption of domestic materials by region (in gigatons per year)
Source: Prepared by the authors based on Schaffartzik et al. (2014).

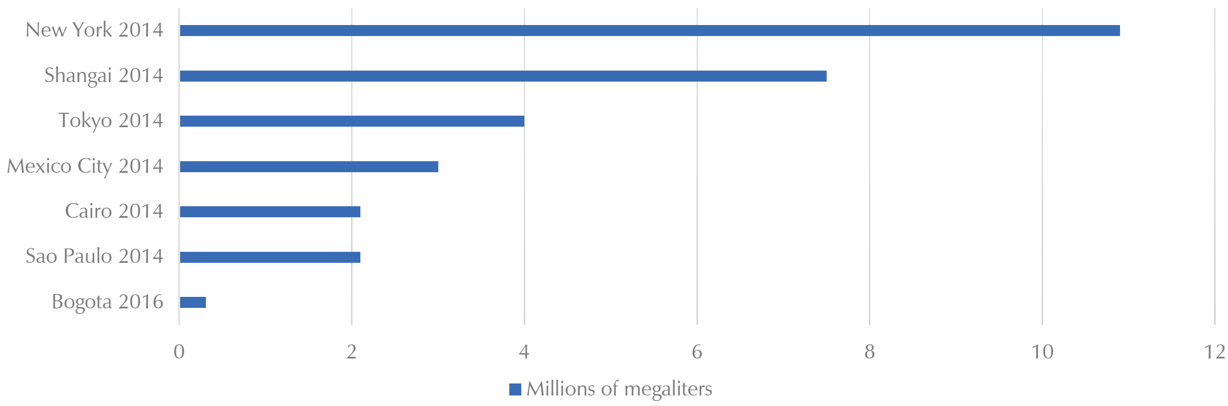


Figure 5. Comparison: water consumption in seven cities
Source: Prepared by the authors based on Kennedy et al. (2015) and Jiménez and Santana (2017).

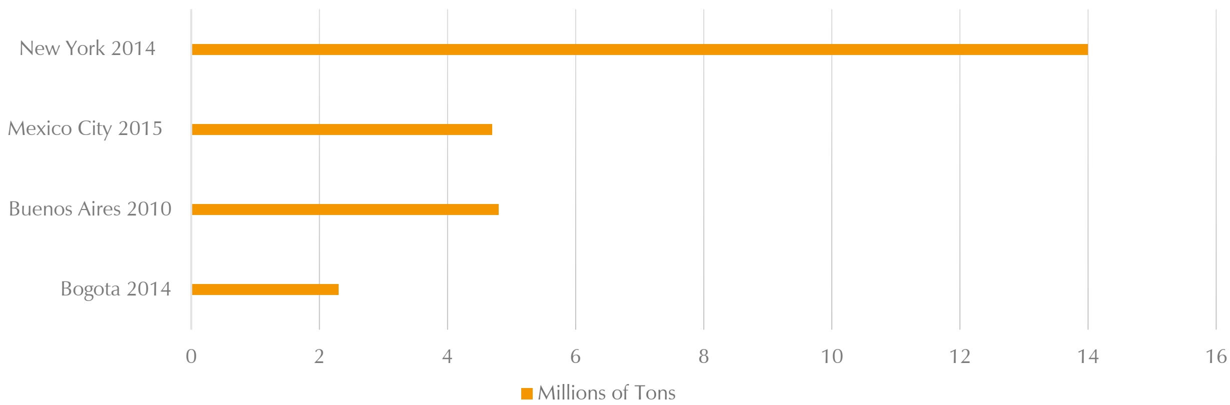


Figure 6. Comparison: production of solid waste in four cities
Source: Prepared by the authors based on various sources (2018).

water supply of 110 liters per inhabitant/day was provided in 2016 (Jiménez and Santana, 2017). That is, the city consumed 0.321 million ML that year (Figure 5).

Outputs

In cities, energy, materials and water are transformed to generate goods or services that sustain the normal functions of urban life. Yet, transforming them generates a series of unwanted externalities: i) air pollution generated by fixed and mobile sources; ii) solid waste (organic and inorganic) resulting from industrial, commercial and residential processes; iii) debris generated by the construction industry or by demolition of obsolete buildings; and iv) liquid waste from industry, housing, commerce and other activities, such as recreational or educational activities.

In direct relation to the characteristics of each city—scale, area, population and level of development—a specific amount of externalities are generated. For example: regarding greenhouse gas emissions, New York produced the equivalent of 55 million tons of CO2 in 2011; Mexico City, 30.7 million in 2012; Buenos Aires, 15.6 million in 2008; and Bogotá, 6.7 million in 2014. Regarding solid waste, New York produced 14 million tons in 2014; Mexico City, 4.7 million in 2015; Buenos Aires, 4.8 million in 2010; and Bogotá, 2.3 million in 2014 (Figure 6). In addition, Bogotá generated 223 million cubic meters of wastewater in 2014, and 12 million tons of debris that same year (Government of the City of Buenos Aires, 2009; González, 2010; City of New York, 2011; Government of Mexico City, 2012, 2015; Alfonso and Pardo, 2014).

Bearing in mind that the massive exploitation of natural resources is totally unsustainable because the global system is confined to a limited area and is therefore finite, and considering that emitting pollutants into the atmosphere, pouring liquid waste into lakes, rivers and oceans, and dumping solid waste into the biosphere are all detrimental, not only to ecosystems and biodiversity, but also to the human species, this article sets out the model for a Multidisciplinary Loop for Urban Sustainability.

Metodology

The investigation had four stages: i) preparation of the procedural model, establishment of the time window, sample selection and instruments of analysis: the systematic review of scientific books and articles was established as a procedural model; a time window was established from the first industrial revolution in the eighteenth century[3] to 2017; Bogotá was chosen for the sampling (data concerning energy, material and water requirements, as well as the production of externalities) because it is the city where the research objectives are focused; and comparative analysis was determined as an instrument of analysis; ii) obtaining knowledge about the object of study: a systematic search[4] for theoretical proposals for strengthening urban sustainability was conducted—in accordance with the previously defined time frame—with an emphasis on those that seek to reduce the urban demand for energy, materials and water, as well as those that aim to minimize the production of negative externalities; iii) information analysis and interpretation of the results; and iv) formulation of the proposed Multidisciplinary Loop for Urban Sustainability.

Results

Although the main research was developed in three fields (architecture, industrial engineering and psychology) no limitations were established in regards to other disciplines: an exploration was conducted in various disciplinary, interdisciplinary and multidisciplinary fields. Through this investigation, eight theoretical concepts[5] were selected that arose from: mathematics, geometry, graph theory, systems theory, health sciences, sanitary engineering, urbanism, urban planning, industrial engineering, ecology, economics, industrial design, commerce, psychology and architecture, among other disciplines. These concepts are presented below in chronological order according to their date of conception. A succinct description is provided for the origins and evolution of each concept.

1. The Closed Loop

The concept of a closed loop arose in the fertile fields of eighteenth-century mathematics and geometry. In 1735, the Swiss mathematician Leonard Euler proposed a circuit, or "closed path," that passes through each corner of a given polygon exactly once. This provided an answer to the famous problem of the Königsberg bridges[6] while simultaneously creating the foundations for graph theory. More recently, general systems theory, as proposed by Bertalanffy (1993), has formulated two types of systems: open and closed. Thermodynamics is applied specifically in closed systems.

The closed loop concept is currently applied to countless disciplinary fields: robotics, computer science, artificial intelligence, medicine, thermal comfort, mechanical ventilation, thermodynamic control and value networks, among others. According to Guide and van Wassenhove, the foundations of the closed loop concept in the field of industrial engineering were established in the mid-1990s, and since then they have been applied to a variety of recycling and reuse efforts, e.g. acquisition of used products, reverse logistics, remanufacturing, repair, and remarketing. These authors propose five phases in the evolution of the concept and its application in industrial engineering: i) *the golden era of remanufacturing,* which had its peak in the early 1990s; ii) *from remanufacturing to an appreciation for reverse logistics,* which gained importance during the first years of this century and fundamentally contributed to solving a series of economic and ecological problems; iii) *coordination of the reverse supply chain,* which provided a better understanding of how to design downstream and upstream channels, led to better decisions in the flow of upstream products, facilitated interaction between new and remanufactured products, and reduced the return rates for blue-ribbon clients; iv) *Closing the cycle,* an integrated design perspective, which has important implications for

3 At that time, nascent industrial cities began to rely on the mass exploitation of natural resources, and urban industrial processes began to pour huge amounts of externalities into the environment

4 This search follows two conceptual guidelines established by the United Nations: "To be in compliance with the minimum waste standards, cities must meet two prerequisites: minimization of the use of fossil fuels and material inputs, and the maximization of recycling and the reuse of energy, water and materials" (United Nations, 2008, p. 156).

5 These eight concepts were selected because they have as objectives: i) a reduction in natural resource extraction; ii) a reduction of externalities. Additionally, they were chosen because they have generated a broad and current research corpus that is reflected in innumerable books, theses and scientific articles.

6 In the eighteenth century, the city of Königsberg, which belonged to East Prussia at the time, was divided by the Pregel river. There were seven bridges crossing the river and connecting two islands. For decades, the inhabitants of the city tried to find a route that would cross each bridge once, and only once, before returning to the starting point (Núñez, Alfonso, Bueno, Diánez and Olivenza, 2004).

the market, but requires the recognition and participation of a large number of independent actors who need to be coordinated to be able to fulfill the economic potential of the system; and v) *prices and markets,* the current phase linking the concept to a wide variety of disciplines because, if prices and markets are not fully understood, they can become barriers or constraints, no matter how well-designed the operating system may be (2009). This phase is just beginning and is spearheaded by green markets.

2. Urban Metabolism

The concept of "urban metabolism" was coined by the American scientist, inventor and professor Abel Wolman. He presented his ideas in an article published in 1965 entitled "The Metabolism of Cities." Wolman proposed two ideas: i) that cities have a set of metabolic needs that support their inhabitants, such as food, fuel, clothing, durable goods, construction materials, or electrical energy; and ii) that the metabolic cycle is only complete when the byproducts and waste caused by daily activities are removed and disposed of without creating danger or discomfort for the inhabitants of a city. Wolman questioned the traditional methods used in American cities to dispose of waste. He noted the high rates of air and water pollution and focused his study on what he called the three most acute metabolic problems: providing an adequate water supply, effectively disposing of wastewater, and controlling the contamination of water and air (1965). Wolman's proposal was dismissed by the scientific community for several decades, but recently it has garnered a lot of interest from urban planners and other scholars of urban phenomena who have now rescued and reevaluated urban metabolism. It is currently considered essential for the development of sustainable cities and communities. Urban metabolism has been defined as the total sum of technical and socio-economic processes that occur in cities, which is expressed through urban growth, energy production and the elimination of all types of waste (Kennedy, Pincetl and Bunje, 2011). Apart from materials, energy and water, other authors link socioeconomic variables to urban metabolism, as well as pollutant vectors like carbon emissions (González, Donnelly, Jones, Chrysoulakis and Lopes, 2013). Another line of research uses it as a tool to find urban and regional planning systems that are more sustainable, because it allows us to understand the way in which urban development impacts the local, regional and global environment (Conke and Ferreira, 2015). Finally, other researchers propose a very recent concept: "intelligent urban metabolism." Thanks to ICT, this concept provides a way to assess the real time flow of matter and energy in an urban setting (Shahrokni, Lazarevic and Brandt, 2015).

3. Circular Economies

In 1970, Kneese, Ayres and D'Arge published the book Economics and the Environment: A Materials Balance Approach. In it, they underscore the negative environmental effects of industrial externalities. For primitive man, the world and its resources were unlimited, but for twentieth-century civilizations they had ceased to be. They introduce the concept of "material balance" by proposing that the flow of materials be managed and channelled in direct relation to their economic value. In 1990, the English economist David Pearce introduced the concept of sustainable, green or environmental economics, which went against the characteristic anthropocentrism of neoclassical economic theories. Based on this new environmental perspective, he defined four basic functions of the environment: i) comfort; ii) natural resources; iii) waste absorption, or the "sink function;" and iv) the support of all life forms. Pearce, in collaboration with other researchers, laid the foundations for the circular economy through a series of books where he identified twelve variables: production, consumption, capital goods, utility, natural resources, recycling, waste, exhaustible resources, recyclable resources, assimilative capacity, harvest and yield (Pearce, Markandya and Barbie, 1989; Pearce and Turner, 1990).

Recently, the field of circular economics has significantly expanded. In brief, its main benefits are: i) a transformation of the role of resources within the economy; ii) the conversion of industrial waste into material for other industries; iii) the reparation, reuse or improvement of products at the end of their life cycle, instead of discarding them; iv) in a world characterized by high prices and volatile markets for resources, it offers huge business opportunities; v) if its implementation is accelerated through public policies, it can mitigate climate change, water scarcity and other global challenges; and vi) it can alleviate tensions around access to resources and supplies (Preston, 2012). As is, the transition to a circular economy has only begun. Its interdisciplinary framework offers good prospects for improving, or changing, current production and consumption models that are considered obsolete due to their environmental impact and the social inequality they generate (Ghisellini, Cialani and Ulgiati, 2016). Ideally, the circular economy should create "autonomous production systems in which materials are used again and again" (Genovese, Acquaye, Figueroa and Koh, 2017,

p. 344). These authors, like many others, highlight the close relationship between circular economics and industrial ecology.

4. Industrial Ecology

According to Watanabe, the term "industrial ecology" was coined in 1971 by a research group from the Japanese Ministry of International Trade and Industry (MITI)(1994). Since then, it has come to define the industrial policy of that country according to the following precepts: i) a recognition of the limits of the system (the world), because it is ultimately confined to a limited area: planet earth; ii) a recognition of the internal relations of the system, because each organic and inorganic substance contributes to the stability of natural planetary cycles through complex relationships; iii) a recognition of the externalities of the system, because they play a very important role in maintaining the balance or imbalance of the system; iv) a recognition of the cause-effect relationships of the system in order to maintain balance, especially relationships established between human activities and the environment; and v) a recognition of the need for self-control, seeking an ideal balance between human activities and the operative limits of the system.

It should be stressed that the concept of industrial ecology is derived from two disciplines: ecology and systems theory. Under the postulates of these two disciplines, it seeks to study the development and behavior of industrial systems from the perspective of the evolutionary patterns of natural systems, which include: a closed loop of materials, evolutionary principles, system resilience and dynamic feedback (O'Rourke, Connelly and Koshland, 1996). Although there are many authors who have contributed to the concept of industrial ecology, the objectives established by John Ehrenfeld in 1994 remain current: i) the improvement of metabolic pathways for industrial processes and the use of materials; ii) the creation of closed loop industrial ecosystems; iii) the dematerialization of industrial production; iv) the systematization of energy use patterns; v) a balance between the capacity of natural ecosystems and materials and industrial products; vi) aligning policy with the long-term evolution of industrial systems; and vii) the creation of new structures for coordinated action using communicative and informative connections (p. 16).

5. Value Networks

The “value network” originated in the distribution and marketing fields of the 1980s, and it subsequently began to include other links in the production chain (Gibson, Hanna, Defee and Chen, 2014). From an organizational perspective, the value network emerged from the integration of a wide variety of interrelated activities that were initially fragmented. Regarding definitions, early on it was defined as a network of organizations that are involved through up and down links, in the different processes and activities that produce value in the form of products and services delivered to the final consumer (Christopher, 1992). For its part, the Council of Supply Chain Management Professionals understands the concept as the exchange of materials and information in the logistics process, which extends from the acquisition of raw materials to the delivery of the finished product to the end user. All vendors, service providers and customers are links in the value network (2010). More recently, the value network has been defined as a series of integrated companies that must share information and coordinate physical execution to ensure an effective flow of goods, services, information and money (Coyle, Langley, Novak and Gibson, 2013). Other authors link a multiplicity of members and channels to the concept of value network. They highlight the flow of resources back and forth—“downstream” and “upstream”—and point out that customer requirements are met thanks to the operation and dynamics of the system, which involves all participants in the network(s)(Stock and Boyer, 2009). Finally, it should be stressed that there are no networks of equal value. Their differences depend on factors such as their structure, the industry sector, the geographical scope of the activity, and the variety of products, compliance methods and patterns of demand.

6. Reverse Logistics

One of the first descriptions of "reverse logistics" was made in regards to industrial engineering: "Going the wrong way on a one-way street, because the vast majority of product shipments flow in one direction" (Lambert and Stock, 1981). This description resembles the one put forward by Murphy and Poist in 1989: "the movement of goods from the consumer to the producer, along a distribution channel" (cited in Rogers and Tibben-Lembke, 2001, p. 129). Three more definitions were coined in 1998: i) it is the role of logistics in product returns, supply reduction, recycling, material substitution and reuse, waste product elimination and renewal, repair and remanufacturing (Stock, 1998); ii) it is the process by which companies can be more environmentally efficient through recycling, reuse and reducing the amount of materials they use (Carter and Ellram, 1998); and iii): “It is the process of planning, implementing and controlling the efficient and profitable flow of raw materials, in-process inventory, finished products and related information from the point of consumption to the point of origin, with the purpose of recovering the associated value or defining its adequate regulation" (Rogers and Tibben-Lembke, 1998).

In the 21st century, the concept has evolved quite a bit. In 2003, the Council of Logistics Management defines it as, "The process of moving goods from their final destination to another point, with the purpose of capturing value that a product would not otherwise be able to appropriate" (Don and Doldan, 2010, p. 220). On the other hand, Cure, Meza and Amaya conceive it as:

> The process of planning, developing and efficiently controlling the flow of materials, products and information, from the last link of the value network to the point of origin, so as to satisfy the needs of the consumer, recovering the waste obtained and managing it so that its reintroduction into the supply chain is possible, obtaining an added value or adequately eliminating it (2006, p. 186).

For Cabeza, reverse logistics "covers the set of logistic activities that include collection, disassembly and dismemberment of already used products or their components, as well as different material types and states, in order to make maximal use of their value in the broad sense of their sustainable use and their ultimate destruction" (2012, p. 26). Finally, Dyckhoff, Lackes and Reese consider that reverse logistics includes all activities related to the handling, processing, reduction and disposal of all hazardous and non-hazardous waste generated by the production, the packaging and the use of a product, which includes the inverse distribution process. They also highlight the ecological function, because reverse logistics can aid in the elimination of innumerable negative environmental impacts (2013).

7. Environmental Psychology

The term "environmental psychology" was coined by the Hungarian psychologist Egon Brunswik in an article published in the Psychological Review in 1943. Thus began the first phase of this discipline, which was primarily focused on "environment-behavior" relationships, i.e. behavioral changes motivated by the environment. In the mid-1970s, a second phase was established, one specifically oriented toward the behaviors that architectural and urban spaces induce, and in this subsequent development it was given the name "architectural psychology." However, in both phases, only environment-behavior relationships were studied. It was not until the 1990s that a form of environmental psychology developed a relationship to environmental conservation. Thereafter, the preceding relationship was reversed to begin studying "behavior-environment" relationships, i.e. environmental effects caused by human behaviors. So there are two very different approaches to environmental psychology: i) one that analyzes the effects of natural or built environments on human behavior; and ii) one that studies the effects of human behavior on the physical and natural environment.

In relation to the second approach, there are two kinds of fundamental behaviors: responsible behavior with the environment (or sustainable behavior), which seeks to conserve and protect it, and irresponsible behavior (or unsustainable behavior), which is destructive and results in environmental degradation. To be clear, human beings are the global agents of environmental imbalance, and because the environmental problems that arose in the sixties and seventies could not be solved by the natural sciences (which had been assumed to be the field that would take charge in these issues), environmental psychology began to play a decisive role in the search for environmental equilibrium and urban sustainability (Baldi and García, 2006; Berroeta; 2007; Pol, 2006, Roth, 2000). Environmental psychology can be defined as "the study of the interrelation of an individual and his or her physical and social environment in its spatial and temporal dimensions," and it aims to identify the processes that regulate the relationship between an individual and his or her environment by revealing the individual's environmental imaginary and attendant behaviors; (Moser, 2003, p. 14).

8. Ecodesign

Ecodesign (also known as environmental design or green design) emerged in the Netherlands in the early 1990s, and the first experiments to apply its principles on a large scale were funded, in that same decade, by the governments of Australia and the Netherlands. A huge number of guides for ecodesign soon emerged from the fields of design and industrial engineering, and by 2003, there were already 26,000 websites dedicated to this kind of environmentally friendly design (Ryan, 2003, 2004). Regarding its definition, Glavic and Lukman conceive of it as "a product development process that takes into account the entire life cycle, and considers environmental aspects at all stages, in a search for products that generate the lowest possible environmental impact throughout their life cycle" (2007, p. 1875). They also claim that ecodesign seeks to reduce the input materials, to minimize negative externalities at the release, and to reduce human health risks, and that it is closely related to the evaluation of the life cycle, to environmental or green engineering, and to processes of reuse, recycling and remanufacturing. On the other hand, Balboa and Domínguez connect it to the circular economy (2014).

In 1999, the Malaysian architect Ken Yeang published the book Designing with Nature: *The Ecological Basis for Architectural Design*, where he addressed all the principles that have hitherto been mentioned about ecodesign. With this publication, he renewed the foundations of architectural design, landscape design and urban and regional planning. In collaboration with Lillian Woo, he also authored the *Dictionary of Ecodesign: An Illustrated Reference*, a book aimed at professionals belonging to a wide range of disciplines to fulfill ecodesign's broad inclusivity. Here follows the entry for ecodesign from the Yeang and Woo dictionary:

> Also known as sustainable design, ecological design of the built environment, green architecture and green design. It is the management of the use of the processes of an ecosystem and its non-renewable resources through eco-mimicry. Its main objectives are physically and mechanically integrating constructed forms and infrastructures with the characteristics and processes of the ecosystem at a given site; preventing the depletion of energy, water and raw material resources; preventing environmental degradation caused by the facilities and their life cycle; and creating a bio-integration between the built environment and the natural environment. It includes any form of design that minimizes destructive environment impacts through a physical, systemic and temporal integration with the living processes of the natural environment (2010, p. 79).

Comparative Analysis

Table 2 presents a summary c comparative analysis of the concepts under review.

1. The concept of a closed loop that emerged in the eighteenth century became part of the theoretical framework for at least six concepts: i) urban metabolism; ii) circular economies; iii) industrial ecology; iv) value networks; v) reverse logistics; and vi) ecodesign.
2. All the concepts studied coincide in two aspects: i) they share the same objectives and ii) they are all part of human, industrial and urban processes.
3. The world is a limited system and its resources are finite. It is imperative that the exploitation of resources be reduced by recovering used products, their materials or their parts so that these can be reintroduced in new production cycles instead of being discarded[7]
4. It is essential to establish green markets where products that have completed their life cycle can be revalued and commercialized.
5. Externalities generated by urban and industrial metabolism affect nature: it is essential to reduce them. Waste that is inevitably generated must be intelligently reused or reintroduced in industrial and urban processes[8].
6. It is essential to recover the energy embedded or incorporated9[9] in the materials that serve as input to the industrial sector and the city, since the generation of this energy not only requires natural resources, but it also results in a large number of externalities.
7. All the organizations and people involved in an industrial or urban process should be integrated so that, instead of remaining isolated, disintegrated and in competition with each other, they share information, establish an exchange of materials and foster cooperation.
8. Every product has an economic, environmental and human value, even when it has reached the end of its serviceable life. It has natural and economic resources invested in it—energy and water, industrial processes and urban processes—and its production generates externalities. Consequently, these should be recovered.
9. To maintain the equilibrium of the natural world, it is necessary to rethink the relationship between human beings and nature, because human beings create the imbalance.
10. It is essential to modify human behaviors—individual and collective—in relation to the environment, so that they are sustainable.
11. The design of a product, an architectural object or an urban space should follow the postulates of ecodesign, which not only takes into consideration the "closed loop," but harmonizes the relationship between the natural and the built world from its beginnings.

Multidisciplinary Loop for Urban Sustainability

The urban, economic, industrial and human processes involved in the normal functions of a city currently require extracting enormous amounts of energy, materials and water that, when processed inside cities, generate a large amount of externalities. In an attempt to reduce the exploitation of natural resources and prevent the degradation of ecosystems and biodiversity, over the past three hundred years, a series of isolated concepts aimed at renewing the balance between nature and the human species have emerged within different disciplines.

7 This objective is promoted by linking the real economic value to the flow of materials that run through the city and the industry, including the materials that are part of products that have concluded their life cycle. Thus, the commercial value of the materials can be put to use and the energy embedded or incorporated into them can be recovered.

8 For example, establishing industrial parks where the waste from one industry serves as input for another, as in nature, or reusing the materials or components of certain products, which can be done very simply and efficiently in the case of construction materials.

9 Embedded or incorporated energy is all the energy that was used to manufacture a material, from extraction of raw materials to industrial processing, including all the transportation and distribution requirements.

	Theoretical concepts that strengthen urban sustainability							
	Closed Loop 1735	**Urban Metabolism 1965**	**Circular Economies 1970**	**Industrial Ecology 1971**	**Value Networks 1980**	**Reverse Logistics 1981**	**Environmental Psychology 1990**	**Ecodesign 1990**
Original Concept	Movement that starts at a point, runs through a system and returns to the starting point: *Loop*	A city completes a metabolic cycle that terminates when waste is disposed of without causing damage	Natural resources are *finite*. *Externalities* destroy the environment. Material balance is achieved by linking the flow of materials to economic *values*	The world is a *limited* system. *Externalities* affect the system. A balance must be established in the cause-effect relationships between human beings and nature	Activities related to fragmented production processes should be integrated. Creating the *cycle* and closing the *cycle*	Movement of goods from the consumer to the producer. The completed cycle of a good in reverse	Studying the environmental effects generated by human behaviors. It establishes two behaviors: sustainable and unsustainable	Taking into account the entire life cycle of a product and considers environmental aspects at all stages of the process and lifespan
Evolution of the Concept (21st Century)	*Reusing* products. *Remanufacturing*. Assessing reverse logistics	Totality of technical, economic and social urban processes exhibited in: urban growth, energy production and disposal of all types of waste	Sustainable economy in opposition to the anthropocentric and exploitative approach of the neoclassical model. Identifies four functions of the environment: comfort, resources, waste absorption, and life support	Industrial systems mimic natural systems. Closed cycle of materials. Resilience. Improves metabolic pathways in industrial processes and use of materials. Closed cycle industrial ecosystems. Dematerializes industrial production	*Exchange of materials and information* in the production process of goods and services. Network of organizations involved through ascending and descending connections. Upstream and downstream	*Returning* products. *Reducing* the necessary materials. *Recycling*. *Renewing waste*. *Repairing*. *Remanufacturing*. *Reintroducing* waste into the production chain. Taking advantage of the *value* of discarded products	Studying of the *interrelation of an individual and his or her physical and social environment* in its spatial and temporal dimensions	Physical and mechanical *integration* of *built* forms and *structures* with the characteristics and *processes of the ecosystem* at a given site

Ⓐ Table 2. Theoretical concepts that strengthen urban sustainability, comparative table

Source: Prepared by the authors based on various sources (2018).

Unfortunately, these theoretical concepts that are so valuable for achieving environmental equilibrium have been kept in different disciplinary fields: isolated, separated, encapsulated, encrypted, closed-in on themselves, or better: embedded within the walls of their own disciplines. To the point that, normally, they can only be accessed from within their corresponding discipline. Unfortunately, although they share the same objective, urban and global sustainability, they do not relate to or combine with each other.

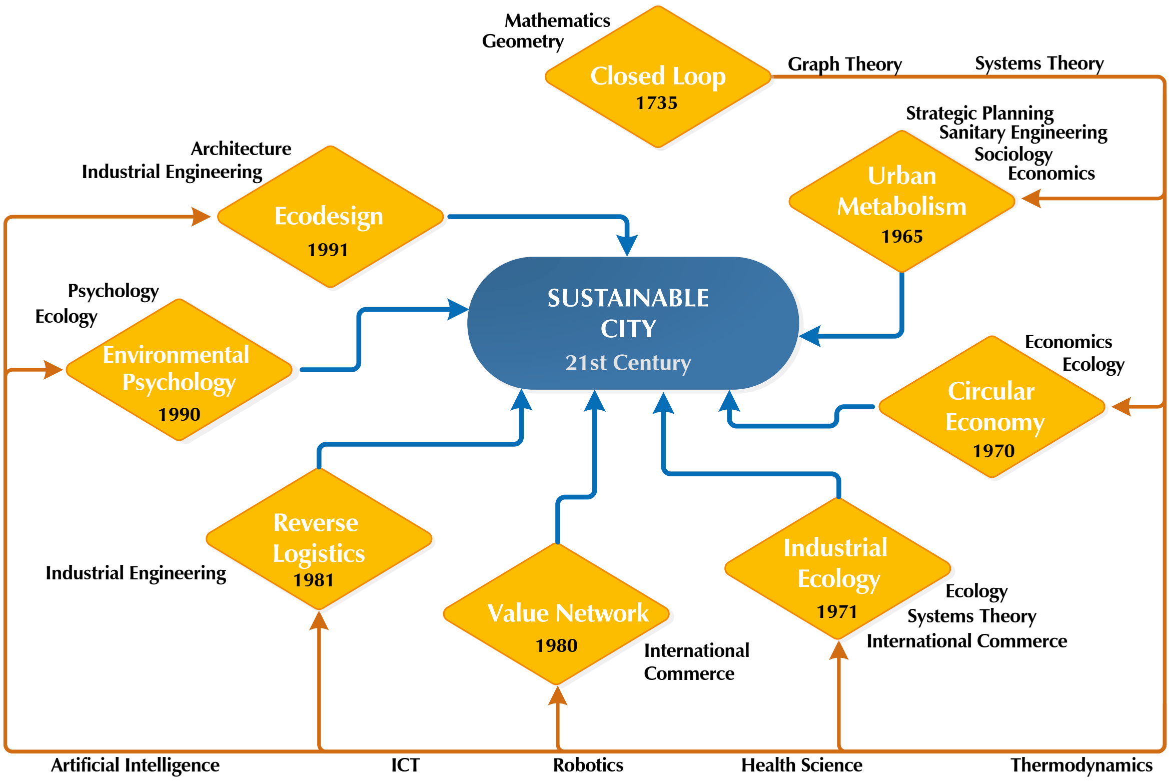
The aforementioned occurs due to the way various disciplines, which only capture a fragmented part of reality, perform their detailed and specific studies. They are artificially created and compartmentalized disciplinary fields where the dominant tendency is to observe an object in fragmented form (Baldi and García, 2006).

Consequently, it is urgent that the concepts that strengthen urban sustainability presented in this article, although historically developed within different disciplines, are now integrated, structured and interrelated so that they can act as a unified and compact multidisciplinary system. As such, they will become more solid, effective and efficient. To unify and integrate them we propose a dynamic model, the Multidisciplinary Loop for Urban Sustainability: eight concepts for urban sustainability that emerged from various disciplines, and that for decades remained isolated, will be unified by drawing a loop around the city to produce arteries of communication between the various disciplines that involve and, by working together, significantly strengthen the sustainability of cities (Figure 7).

It is imperative that each of the concepts and disciplines that constitute the Multidisciplinary Loop for Urban Sustainability begin to interact, understand and communicate with others, even if they belong to or have emerged from different disciplines. When all is said and done, all of them will be integrated into the same reality: the contemporary city.

Discussion

Currently, the literature on urban sustainability tends to list a series of good intentions, either grouped into a whole concept or not. For example: "Vibrant, harmonious and inclusive communities in the social and cultural com-



Multidisciplinary loop for urban sustainability
Source: Prepared by the authors

plex" (Office of the Deputy Prime Minister, 2004); "Maintaining environmental quality and potential, supporting development and socio-economic management, in addition to providing sufficient services and livelihoods to all current and future inhabitants" (Tang and Lee, 2016); "Energy efficiency in public buildings, areas with limited traffic and resource and land management" (Gargiulo et al., 2017); "Reducing economic inequality in neighborhoods" (Sampson, 2017); "Sustainable urban mobility" (Hodson, Geels and McMeekin, 2017); etc. But how do those good intentions materialize?

Other initiatives focus on a single factor of unsustainability, like Transit Oriented Development (TOD)[10], which focuses on mobility and provides partial solutions. But what about the other factors that contribute to the imbalance?

A third group of proposals establishes policies and documents, such as the Urban Environmental Management Policy (MAVDT, 2008), a Colombian guideline that aims to resolve the "the historical lack of integration and coordination among the environmental authorities in Large Urban Centers" (p. 27). This document also defines a sustainable city as being characterized by: "Knowing the natural foundations that support it and developing conservation strategies […] Implementing comprehensive risk management plans […] Contributing to the improvement of the urban habitat to ensure environmental sustainability" (p. 27). But isn't this another list of good intentions that nobody knows how to translate into practice?

In contrast, the Multidisciplinary Loop for Urban Sustainability rests on eight concepts that strengthen said sustainability: the closed loop, urban metabolism, circular economies, industrial ecology, value networks, reverse logistics, environmental psychology and ecodesign. These are concepts that already exist and have been implemented quite successfully in different regions and countries, but the staging has been characterized by individuality, so they function in a disarticulated, disaggregated, uncoupled, and fragmentary way. Though they provide positive results, they are divided nonetheless. Consequently, these concepts do not act in a context (the city), nor do they act as components within an articulated and integrated system. On the contrary, they act as loose wheels. Whatever they achieve, they do so in an isolated and partial way. This proposal for a Multidisciplinary Loop for Urban Sustainability arose precisely as a means to arrange these theories within a complex whole[10] or system whose organizing concept is sustainable development, so that, when it is designed as a tool, it can be applied in cities, municipalities, districts, towns or villages.

10 See the Transit Oriented Development Institute: http://www.tod.org

11 "In a systemic approach, the properties of each part can only be understood from the organization of the whole" (Capra, 1998, p. 7).

E-ISSN: 2357-626X
ISSN: 1657-0308

Conclusions

The cities of the 21st century are going through a period of great change. One of the most transcendent and necessary changes is that professionals and researchers within a discipline, regardless of the discipline, must enter other fields of knowledge, because that exploration allows them to create arteries of communication and interdisciplinary networks that: i) stimulate and fertilize human creativity (Florida, 2009); ii) facilitate the creation of new forms of sustainable action; and iii) contribute to the collapse of the old urban paradigms that not only remain entrenched in the nucleus of society, but also in the perceptions and behaviors of citizens. Obsolete and unsustainable paradigms prevent the attainment of truly equitable and environmentally healthy well-being for all people; therefore, it is urgent they be dismantled. Because, as long as they persist, they will continue to destroy the sources of energy, materials and water that humanity and cities desperately require for their survival: nature.

Therefore, it is a priority that professionals who somehow affect the urban dynamics of contemporary cities—be they designers, architects, urban planners, industrial engineers, civil engineers, transport engineers, hydraulic engineers, economists, sociologists, psychologists, mathematicians, etc—understand and utilize the Multidisciplinary Loop for urban sustainability in their profession. They should analyze and value its diverse and varied components and take them into account when planning activities that can impact the dynamics and environment of urban life.

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