Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development

Chaham Alalouch · Cristina Piselli · Francesco Cappa
*Editors*

# Towards Implementation of Sustainability Concepts in Developing Countries

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# Advances in Science, Technology & Innovation

## IEREK Interdisciplinary Series for Sustainable Development

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Francesco Cappa
Editors

# Towards Implementation of Sustainability Concepts in Developing Countries

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# Series Editor's Preface

Sustainability is a major concern nowadays—an attempt to reduce carbon emissions, protect environments and keep the delicate ecosystem of our planet in balance. To improve sustainability, the consumption of non-renewable resources has to be decreased to help nature replenish and suffice itself. Moreover, conserving the energy and taking the environment's well-being into consideration are considered to be key roles in improving sustainability.

This book, on Sustainability and its Impact on Developing Countries, contains selected research from the International Conference on Improving Sustainability Concept in Developing Countries (ISCDC)—4th Edition, which was held in Cairo, Egypt. Research from the conference has undergone a rigorous review process thanks to the book editors and scientific committee of reviewers. The book contains several topics regarding sustainability concepts in architecture and urban design, and sustainable design strategies for economics, and environmental and social dimensions. Making this book a great opportunity to help evolve our built environment and also explore new and different approaches with the hope to improve sustainability in different developing communities and countries.

Through this book, readers will be exposed to a number of case studies around the world: from Middle Eastern countries to India, Bangladesh, China and more. It stimulates discussions on planning and design strategies in the development of a sustainable city. It aims to educate readers about the important issues and solutions related to sustainability such as improving the quality of life and built environment in developing countries, poor and rich cities alike.

The book will benefit an array of readers from different backgrounds due to its interdisciplinary nature. It succeeds in bringing together fields such as architecture and urban planning, landscape architecture, environmental preservation and other environmental processes. It is highly recommended to academics, postgraduate students and interested readers.

Mourad Amer, Ph.D.
Series Editor, Springer

CEO and Founder, IEREK Cairo Egypt

# Preface

Over the years, more countries have started realizing the threat facing our planet—from vanishing species, to catastrophic effects of climate change and depletion of our resources all of which have led to increasing investments in a more sustainable future. According to the Human Development Report by the UN Development programme (2016), more sustainability programmes are being initiated around the Globe. However, as our countries grow more industrialized, the risk of further contribution to an increase in emission levels and environmental degradation remains imminent. Despite recent advancement, there is still more progress to be made and additional room for investment in sustainable practices and strategies, especially in developing countries.

The building and construction industries are among the largest consumers of energy, materials and water, thus there is a great opportunity to achieve sustainability if proper strategies and actions are put in place to make building and construction activities more sustainable. Doing so will give people the chance to live in a healthier environment with improved environmental, social and economic conditions and better quality of life. This book represents an attempt to contribute to the improvement of the sustainability scene of the built environment in developing countries by presenting recent research and case studies from several countries covering the Middle East, Asia, and Africa, and discussing pressing issues related to environmental, social and economic sustainability. The book features 25 chapters structured in three parts: urban sustainability; sustainable building design; and sustainable development management, impact, and education. The first part of the book focuses on strategies for urban sustainability. It features nine chapters representing research and case studies from several developing countries such as Iraq, Egypt, South Africa, Rwanda, Bangladesh, and India. Through these chapters, the reader will learn about the challenges of modern cities and the corresponding state-of-the-art sustainability strategies that could mitigate the negative impact of our cities and improve sustainability practices at the urban level. Issues discussed include urban forms, outdoor thermal environments, urban building blocks, livability, bike routes optimization, TOD, green spaces design, and more.

The second part of the book provides insights into sustainable design strategies at the building level. It includes ten chapters addressing a range of topics that are important to researchers, professionals, and policymakers who have an interest in design strategies for sustainable buildings. The chapters discuss design strategies for several building types such as office buildings, housing, rehabilitation centers, elderly care facilities, hospitals, and more. These design strategies were discussed by the authors from several angles including, but not limited to, materials, building envelop design, pro-environmental behavior, adaptive passive interior design, ventilation, prefabrication and industrialization, and visual comfort.

The last part of the book extends to cover issues related to sustainable development management, impact, and education. It includes six chapters ranging from green project management for sustainable development, global neighborhood sustainability certification and its relevance to the developing countries, Global and regional perspectives on accessibility to cooking fuels, solid waste disposal, $CO_2$ emissions, and higher education for sustainability.

Through presenting different case studies, this book explores new topics of sustainable development and design in developing countries. The significance of this book lies in its attempts at implementing policies that coincide with sustainable development in areas that are in dire need of urbanization. The authors of the different chapters in this book reunite once more towards one common goal: contributing to new action plans and innovations that tackle the challenges facing our planet while remaining in line with the UN's 2030 Sustainable Development Goals (SDGs).

Muscat, Oman — Chaham Alalouch
Perugia, Italy — Cristina Piselli
Rome, Italy — Francesco Cappa

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The book Editors would like to thank the authors of the research papers of this book. They would also like to thank the scientific committee of reviewers who contributed with their knowledge and constructive feedback in hopes of ensuring the manuscripts are of the best quality possible. Finally, the Editors would like to express their appreciation to the IEREK team for supporting the publication of this book.

IEREK would like to express its appreciation to all members of the staff and scientific committee for their tremendous efforts and contribution to the growth of this institution and for making our conference on Improving Sustainability Concept in Developing Countries a success. IEREK would like to thank the conference chairperson, Prof. Iman Gawad, Associate Professor of Architecture in the Architecture Department of the Faculty of Fine Arts, Helwan University, who had a hand in making this conference what it is today by providing scientific and logistical support. IEREK takes pride in being an institution that amasses a highly qualified and competent team who restlessly worked for months to make this conference what it is today in hopes of creating a well-rounded society. Last but not least, we cannot neglect the prominent role undertaken by our Editors who made it their duty to help this institution in spreading knowledge to the masses.

# Contents

# Sustainable Design Strategies at the Urban Level

# Toward Resiliency Through Sustainable Urban Formation in Baghdad

Zaynab Radi Abaas

**Abstract**

This research comes in an attempt to develop the present urban patterns toward resiliency in the developing countries' environment in general and the Baghdad City in particular. This is performed through the looking at the most recent theories designed to extrapolate socio-ecological resilient and sustainable urban formation, viewing their roots and development, by founders and advocates. The aim is to extract the most significant strategies from these perspectives that can serve Baghdad City as a case study. The key finding of this research is the lack of the ideal theory that extrapolated the sustainable urban formation as a structure that can be applied as a prototype of the resilient theory. Each city demonstrates the properties that distinguish it from others, and day after day, applications and indicators are undertaken to serve some cities and not others depending on functionality, stability, and adaptive cycling process, the nature of the city, and the environmental characterization of this city. As a result, this research adopts some integrated strategies as solutions combining the recent theories and includes recent approaches searching for Baghdad urban resiliency, by extrapolating its phases of changing, its flexibility, and its adaptation of the urban fabric according to its master plans. Consequently, some cities might have able to cope with the severe spatiotemporal changes and reach sustainability, and others might fail to achieve urban resiliency.

**Keywords**

Urban formation • Sustainable theories • Resiliency • Baghdad

## 1 Introduction

Since the seventies of the twentieth century, sustainability, and resiliency have been the major concern for architects, planners, and specialists. They both have wide controversy. Some of the researchers believe the two terms are identical, or one represents the other, while others see resiliency is adaptable and dynamic, but sustainability is achievable and static (Caputo, 2015). The United Nations in their sustainable development goals is stressed on attaining sustainable, resilient, and flexible cities equally, and used interchangeably (Yamagata & Ayyoob, 2018). Urban sustainability as associated with these terms has lots of applicable theories and seeks to build qualified strategies, indicators, and plans for better futures; however, most of them considered optimizing natural resources use is the solution of urban sustainability (Elmqvist et al., 2019). Resiliency, on the other hand, becomes widely used as an urban development policy, derived from the ability to absorb, reduce, recover, and respond to the disturbance of the socio-ecloogical system (Eraydin & Taşan-Kok, 2013; Yamagata & Ayyoob, 2018), toward the degree of facing, adapting, growing, and working with the challenges in the system or the city keeping its main social, ecological, natural, and technological functions and reorganizing itself (Newell et al., 2016). Additionally, Peres argued the resilient urban system has to have many levels and scales to keep going, starting with the specified level of the ecological and engineering resilience and reaching to the general level, which represents the ability of the system to work with the long-term chronic, slow to emerge stressors of a developing resilience (Peres, 2016). Moreover, resilience and urban form have some theoretical and empirical evidence toward achieving hierarchy and connectivity in multiple city scale (Sharifi, 2019). Still, resiliency insures flexibility and recommended as to be one of the guidelines to achieve solid sustainability, focusing on maintaining the natural resources over a long period of time (Pickett et al., 2019) and (Brand & Jax, 2007).

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On the other hand, several approaches correlate the structural development of urban form with sustainability and the access of resilience. Jabareen, 2006 identified four types of sustainable urban forms starting with compact and eco-forms and adding neo-traditional and containment development. He provided a matrix in seven sustainable strategies which support the specialists to examine and evaluate the desired form in reaching sustainability (Jabareen, 2006). Forgaci and Timmeren (2014) concentrated on the complexity and adaptability of three terms of resilience (general, spatial, and resilient of urban formation). They asserted on fitness, performance, and sustainability to reach better urban resilient. However, they claimed that the principles of sustainable formation were more important than the structure of formation as long as these forms could adapt some synergies to cope with the climate changes and surroundings (Forgaci & Timmeren, 2014). Sanchez et al. (2017) explored several terms of sustainable resilience concepts and thinking depending on the four principles of sustainability-related to the socio-ecological resilience presented by Sanchez et al. (2016) and detected some short- and long-term actions of urban resiliency (Sanchez et al., 2016, 2017). Farther more, Sharifi and Yamagata (2018) argued that enhancing urban resilience could be achieved through hierarchical urban-scale dynamic framework with multiple attributes (Sharifi & Yamagata, 2018).

As a result, many studies tried to find some solutions and strategies to achieve resiliency by applying several synergies to gain sustainable urban forms. This research is a try to find some solutions accompanied by the recent theories and add new approaches, to explain the transformation nature of Baghdad urban form and how to reach urban resiliency.

## 2 Methodology

The structure of this paper explains two perspectives, firstly the debate of resilience-sustainable theories and its foundation, and secondly the theories of sustainable urban forms related to these theories. The idea is to look through the urban formation in Baghdad, its recovery, and adaptation abilities in multiple transformation scale and levels. After that, the paper presents the possibility of urban resiliency in Baghdad and some extracted solutions for sustainable urban forms toward resiliency. See Fig. 1.

## 3 Materials and Methods

The research tries to introduce a conceptual model for urban resiliency in Baghdad following the extrapolating method. The idea consists of an analytical framework to explore the key characteristic of resilience theories gaining the goals of sustainability. It is in an attempt to prove that the spatiotemporal changes in Baghdad City have the ability to reach urban resiliency through its continuation sustainable urban formation. And the diagram below shows the research method in detail. See Fig. 2.

## 4 Literature Review

### 4.1 The Foundation of Sustainable—Resilience Theories and Debate

Many theories had been discussing the sustainable-resilience correlation and their impacts on urban sustainability. Lots of them consider the city as a vital dynamic system, blaming the human being and their activities footprint on devastating the natural ecosystem and the cycling process. Holling, Odums, Fath, and Girardets are among the best- and well-known theories. Holling's interpretation theories had captured several meanings since his seminal paper (1973) of socio-ecological systems and conceptualized resilience as the capacity of a system to retain to balance the following disturbance. He produced many viewpoints on the stability and management of resiliency (Holling, 1973). After a while, he developed the adaptive cycle resulting resiliency in multiple dimensions and phases within different scales (exploitation, conservation, release, and reorganization). Later, with his colleagues, he introduced the perspective to clarify the relationship between adaptation and transformation with resiliency. They defined resilience as the ability of a framework to ingest aggravation and rearrange itself while experiencing a change to even now hold basically a similar value and functionality, structure, personality, and response. The most important gaining is to move from the concept of the ultimate goal of gaining sustainability to the functionality of the transformation toward more resilience, adaptive systems, and management (Walker et al., 2004). While Odums Ecological Theory is considered the initial source of the urban sustainability theory that dealt with the city as a living system and tried to link the socioeconomic system with the environment and fit the technological engineering design with the self-ecological system (Odum & Odum, 2003). *The Ecological Theory* was introduced by the scientist H. T. Odum and his brother Eugene P. Odum and described in Odums hypotheses as the thermodynamic orientation or natural tendency that ecosystems follow during succession, supporting the field of ecological engineering and benefit from resiliency, adaptability, mutuality, and facilitation (Mitsch, 2018). Progressively, environmental and planning scientists including Fath et al. viewed ecosystem succession as a series of four growth and development stages: boundary, structural, network, and informational (Fath et al., 2004). Even more, Fath (2017) argued sustainability could be

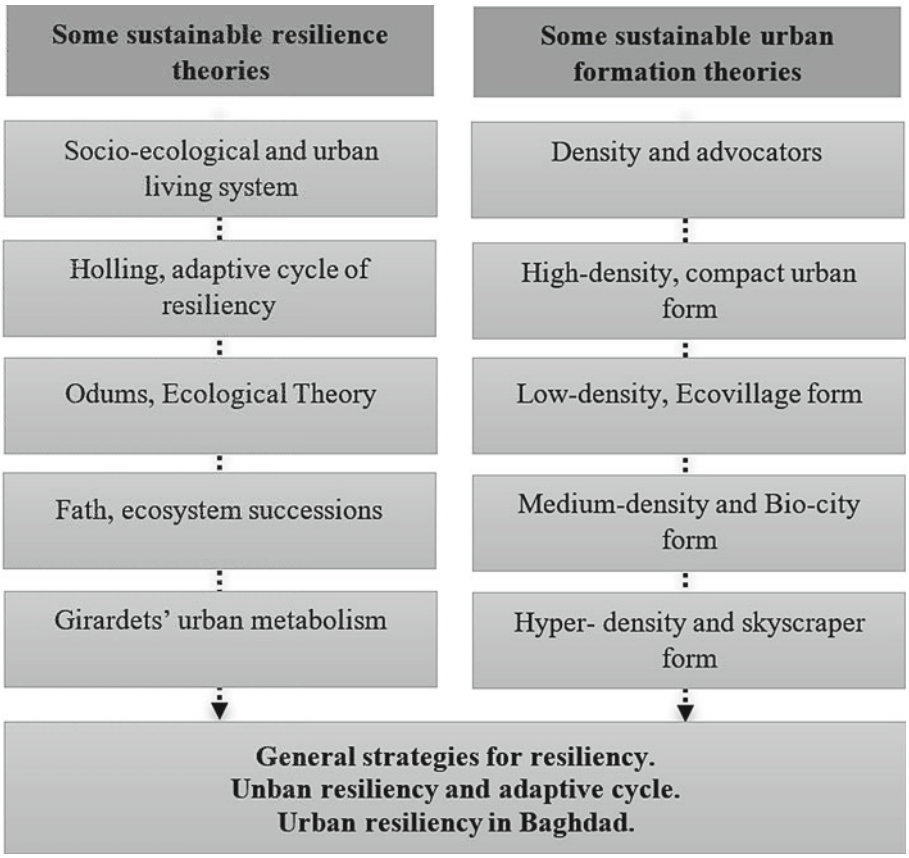



**Fig. 1** Graphical framework shows the structure of the paper

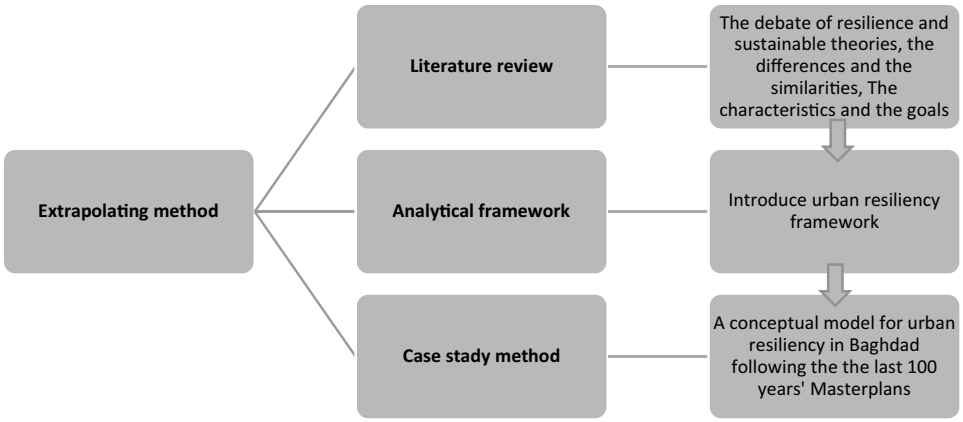



**Fig. 2** Method of the research paper

shown by how the ecological system is a complex, adaptational, functional structure and can generate, tolerate, and preserve its dynamic activities (Fath, 2017). On the other hand, many researchers have thought that achieving a sustainable urban system must be linked to the surrounding environment provided by the formative nature of its constituents, as any ecosystem nurtures species structures. These theories started to identify the city as an ecosystem in the sixties of the last century. Its beginning with the ideas of Abel Wolman (1965) whom connected different types of resources called the consumer and the digester or input–output according to a holistic view to the city as a bio-system (Wolman, 1965). Recent methods to analyze urban ecosystem has been presented, biological, spatial, social, and energy flow of urban metabolism and footprint analyses (Piracha & Marcotullio, 2003). After some time, the urban ecosystem scientist Herbert Girardet indicated the possibility of dealing with those energetic inputs as flows entering and exiting the urban environment. This can be observed in the circuit metabolic in nature (*ecosystem metabolism*) (Girardet & Miguel, 2009). The idea of the circular, regenerative metabolism is to reduce the amount of waste through the

process of recycling, to enhance the environmental relationship between the ecosystems and the urban structure, and as a result, to promote urban community establishing a self-efficient, regenerative city (Girardet & The World Future Council, 2013).

## 4.2 Sustainable Urban Formation Theories

From above, the challenges to resilient, sustainable living have been discussed and developed over time. And as mentioned previously, many resilient, ecological, and/or urban metabolism theories, along with others, have been dealing with urban formation as a living dynamic system with the natural inputs and outputs of the energetic urban processes like human activities or environmental forces. Therefore, each of them has taken as a base to adopt various kinds of solutions through different kinds of schools. Some of the urban planners and thinkers today are centered on the idea of urban metabolism and the possibility of taking the compact city and the high-density places. The main concept is to reduce the city's consumption of the goods, energy, and food at high rates, and the environmental pollution. A pivotal debate from the other planning schools' thinkers goes toward the ecological theory with the theme of the eco-village and low-density urban form. The third theory of bio-city can rectify the same energetic consuming and depleting problems by adopting the idea of the integration between the man and his environment as a holistic system. Finally, the hyper-density theory comes solving the urban degradation.

### 4.2.1 High-Density, Compact Urban Form

Most people studied, saw, lived, or walked through the narrow roads, the Shanshuls, and the courtyards of the compact Arabic city. After hundreds of years, this idea comes again raising a wide controversy about the ability of these cities to reduce or balance the ecological footprint at the urban scale (macro- and micro-scale). By the 1970s, researchers noted that factors advocating higher densities included "nearness to the central area, place of work, transport facilities or an open space" and that within an overall density standard there could represent variations within a development. In the next decade, similar arguments were reinforced, and some were included. Central to the guidance on increased density was the preservation of suitable agricultural land, the prevention of urban sprawl, and the protection of the countryside all of which point to the need for compact development (Jenks & Dempsey, 2005). Rogers (British architect famed for his modernist and functionalist designs) (Astbury, 2019) went toward the concept that the compact or "dense city" model can be adapted to a circular metabolism. That is "where consumption is reduced by implementing efficiencies, where re-use of resources' energy for transport by increasing the viability of public transportation and by reducing distances between facilities, so encouraging walking and cycling is maximized." Rogers (1997) also described the compact city by saying "Urban areas are organized in concentric bands of density, with higher densities around public transport nodes (rail, bus and underground stations)" (Rogers, 1997). According to (Burton, Jenks & Williams, 1996), the compact city could be related to the mixed-land uses and high-density development, along with a convenient public transportation infrastructure, which encourages people to walk and cycle rather than to drive their cars, go some way toward realizing aspirations for the sustainable city. The UK Government published, in 1999, *a strategy for sustainable development* in the UK, and *toward an urban renaissance strategy*. In *toward an urban renaissance,* the report of the Urban Task Force (UTF) very clearly sets out the thinking on the design of sustainable urban form. The current orthodoxy sees the city that approximates to a sustainable form, as a compact and flexible structure in which the parts are connected to each other and the whole, with a clearly articulated public space. The public realm connects the different quarters to each other across the city, while also linking homes to workplaces, schools, social institutions, and places of recreation. The main features of the compact high-density model, outlined in the report of the UTF, *toward an urban renaissance* include (Rogers, 1997):

- High-density mixed-uses development with mixed tenure housing at fifty units per hectare (Mitsch, 2018).
- Development arranged around centers with most homes being within 10–15 min' walking distance from a center.
- These semi-autonomous communities, self-supporting in daily needs, are connected to other centers and to the city main center by public transport routes.
- An important structuring element represents a well-connected public realm of streets, squares, parks, and other open spaces with green areas (Abaas, 2008).
- Additionally, urban managing, designing and regenerating, social well-being, and environmental and ecological balancing were among their targets (Regan, 2000).

Although the name and the properties of the compact cities are extremely close to the Arabic Islamic cities, neither the environmental factors nor the cultural habits allow (what) to build high-rise buildings with more than 3–4 story building. However, the studies demonstrate the ability to reach resiliency through various solutions as synergies of the compact cities. The relationship that the high-density, mixed-land uses of the compact city has on accessibility to local facilities is to provide local facilities that are located

within walk distances from one's home reducing the necessity of owning and using private cars prompting the public participation and enhance livability (Jabareen, 2006). It, therefore, follows that the most efficient way in which to make this work is by ensuring that the densities of urban areas are high enough to support services and facilities locally adapted (including public transportation, green infrastructure, passive design, and greening the urban area), and large enough to persuade employers to the area to capitalize on the workforce in the area.

### 4.2.2 Low-Density, Eco-Village Form

In 1991, the American thinker Robert Gilman and his wife Diana introduced a definition of an eco-village that became widely known in sustainable communities. They defined an eco-village as settlements or cities, in which the community is connected to their natural environment and lives in healthy sustainable development. The aim is to regenerate integrated social and natural environments (Zeybek & Arslan, 2017). In this view, achieving sustainability is not enough; it is vital also to resilient the social and environmental fabric of life, and across all four dimensions of sustainability: social, environmental, economic, and cultural. In 1995, a global initiative called global eco-village network (GEN) supporting the similar ideas. Lastly, GEN concentrates on peaceful life, social justice, and ecological support (Maharani, 2019).

At one time, the term "eco-village" is specifically used to identify low-density settlements in which the traffic routes are widely spaced, and the villas are occupied by wide open spaces consisting of farmland, intensive market gardens. The frontage onto the main roads is a linear strip of buildings and other activities (Moughtin & Shirley, 2005; Maharani, 2019). As a result, eco-village considers an urban development designed to provide an ecological sound and community-oriented alternative to regular individual or impersonal residential housing. Eco-village groups were to respect and restore the native biodiversity of the site. It was decided that only 15% of any site would be built-on while the rest would be landscaped or farmed (Sassi, 2006). However, the advocated planners of the eco-villages cities hope to change the indicator that measures sustainability by the proportion of common land uses and have a new sustainability indicator measuring people's satisfaction with the urban environment. In addition to their intention to have required standards for the quantity and accessibility of urban open spaces, they have a strong ambition to have a target for the proportion of managed urban land in designated greenway strategies. Moreover, they look for more imaginative green space design, habitat creation, river and wetland restoration, and sustainable drainage (Moughtin & Shirley, 2005).

From his studies of the urban forms, Jenks (2005) claimed that the historical pattern results in a net density of 2.8–3.4 units per net acre (6.9–8.4 per hectare), including the alley and a proportional share of the adjacent city streets, but not including other commonly shared public amenities like parks and schools. It can be noted that the low-density standard of 12 or 8 houses per acre in rural areas (20 or 30 houses per hectare), became the norm for the inter-war period and influenced the spread of a uniform suburbia (Mike & Nicola, 2005).

The benefits of the eco-village idea had echoed the earlier pronouncements of Ebenezer Howard and the concept of the "Garden City" and the Garden Cities of Tomorrow, which contains a wealth of ideas for urban development. The eco-village houses followed counteracted health risks ideas by, ensuring healthy indoor air quality by minimizing the use of toxic materials, materials containing organic compounds; ensuring all internal spaces have abundant natural light, and encouraging residents to spend time outside and to enjoy nature (Sassi, 2006). Another benefit from designing and contacting houses with nature is visually and physically reconnects with the outdoors. All windows gain views of the surrounding natural environment and shaded verandas off the living rooms. The site location and design also encourage interaction with nature. By positioning the car parking away from the houses, a few minutes' walking in nature is assured each time one leaves the home. More dynamic interaction is equally possible through the reforestation work, the removal of invasive species, and the general maintenance of the site, as well as the independent gardens (Sassi, 2006). In addition, those who advocate these forms of development pointed out that low densities have many advantages for sustainable development, by installing solar heating for each home, the possibility of extensive vegetable gardens, and recycling of organic' domestic wastes. So, the goal of which represent the harmless integration of human activities into the environment in a way that supports healthy human development in physical, mental, and spiritual ways and is able to continue into the indefinite future (Kasper, 2008).

In summary, it receives a significant role in social transformability toward respecting the natural life and living in sociocultural coherent in human scale settlements (Christian, 2007; Dias et al., 2017). As a result, the new natural and eco-technological integration with the urban environment is best describing the eco-village concept today in multiple urban scales, to get the self-resilient healthy system (Mohan et al., 2017).

### 4.2.3 Medium-Density, Bio-City Form

After describing the most fundamental properties, advantage, and disadvantage for two famous kinds of the urban forms' adaptation, Moughtin (an architect who authored many books concerning urban form and urban design) suggested a different pattern of sustainable urban form which reduces most of the other forms' defects and combines their

benefits. He described his thoughts in the bio-city concept as a combination of compact eco-structures in sustainable urban formation. Adopting medium-density development produces the similar concept of the public transport, smart technologies, integrated green systems, mixed-land uses, and a mix of house types, placing the priorities to the needy for open interconnected spaces in the city (Moughtin & Shirley, 2005).

There is a thought that the roots of the bio-city theory and its name return to the *Baubiologie* movement in Germany in the fifties of the last century which adopted the goals of creation a harmonic relationship between buildings and the environment, depending on the inhabitants' spiritual, physical, and biological needs. Moreover, it is very respectful to the idea of considering the building's system like the ecological system in order to provide the protection, and the insulation to the residents, in aim of insuring indoor air quality and comfortable environment (thermal, humidity, colors, light, and human scale). While the *Baubiologie* movement dealt with the passive, active, and renewable earth energies in a concept of introducing healthy living (Sassi, 2006), the same principles have adopted by the bio-theory which concentrates on the biological urban form and healthy environmental interaction between the building and the surrounding.

In fact, many architects support this idea. Some of them urged that it is challenging task of dealing with market-motivated development without neglecting the traditional aspect of compact built-up areas on a green carpet. Further, planning applications and programs for new developments are permitted more easily as long as the overall green area is unreduced; compensation for ruined green spaces is required through the greening of brownfield sites. This means a radical shift from strict and static land-use planning to more flexible and dynamic management of the city region (Mike & Nicola, 2005). In addition, some planners' opinions are that the polycentric model should be adopted to achieve the virtues of both a high-density compact city and a low-density eco-settlement with enormous tracts of green space. Others said that the convergent images of future megacities might show that a sustainable spatial form requires a regional unity (in the centric form) with a polycentric structure (Mike & Nicola, 2005).

So, the bio-city theory came to combine the monocentric with the polycentric concept in a hybrid urban form. It is seeking to create a resilient livable environment respect the needs of the inhabitant overtime.

#### 4.2.4 Hyper-Density and Skyscraper Form

In 2013, architect and planner Vishaan Chakrabarti wrote about what he termed vertical cities as a key to solving the dense cities environmental and urban degradation, and how to transform them into healthy, efficient environmentally sustainable. He brought up the idea of re-planning the existing cities with a hyper-density green buildings environment with multiple functional, mixed-use high-technology vertical, skyscrapers residential neighborhoods. In which, all will live in affordable housing with improved public transportation and subway services. Residents will share their social and recreational services, which improve the quality of living and increase sociocultural values (Chakrabarti, 2013). It has more than five thousand residents per one square kilometer and overall district density reaching 30,000 residents/km2 or more. This will support livability, connectivity, flexibility, and amenity (Bishop, 2017). Others expressed hyper-dense neighborhoods that consist of 500 home per hectare (Gardiner, 2018). However, some critics focuses on the high-compacted and/or hyper-density, built environment could hinder and resist resiliency during emergency disasters for the possibility of more risk exposures (Sharifi et al., 2017). Honk Kong is an example of hyper-dense city with separated multifunctional podium organization buildings system to provide privacy for the residents' area (Lau & Zhang, 2015).

## 5 Analytical Framework

### 5.1 General Strategies for Resiliency

The synergies between various kinds of sustainable urban forms (compact, hyper, low or moderate density) depending on the city nature and population, culture, with the alternative approaches of resiliency (engineering, disaster, socio-ecological, climate change) characteristics might have reform the city toward urban resiliency. See Fig. 3. Hence, urban resiliency is a multidisciplinary, proactive, dynamic approach, addressing, diagnosing, and managing the undesired situation. In which, multiple sustainable synergies with interconnected scales and levels could be applied depending on the urban structure of the city, resulting adaptive, integrative, flexible urban system, ready to respond to the spatial–temporal changes and recover, or sustain or transform its formation structure.

### 5.2 Urban Resiliency Adaptive Cycle

As Holling defined the affecting forces of his adaptive cycle in three dimensions of connectedness potentialities and resiliency (Holling, 2001), many studies wrote about these disturbing factors that could alter or transform the state of the city (Azevedo, 2016; Galderisi, 2014; Suárez et al., 2016). Resulting from this, and due to the multiple functional urban resilience system natures, each city has its own

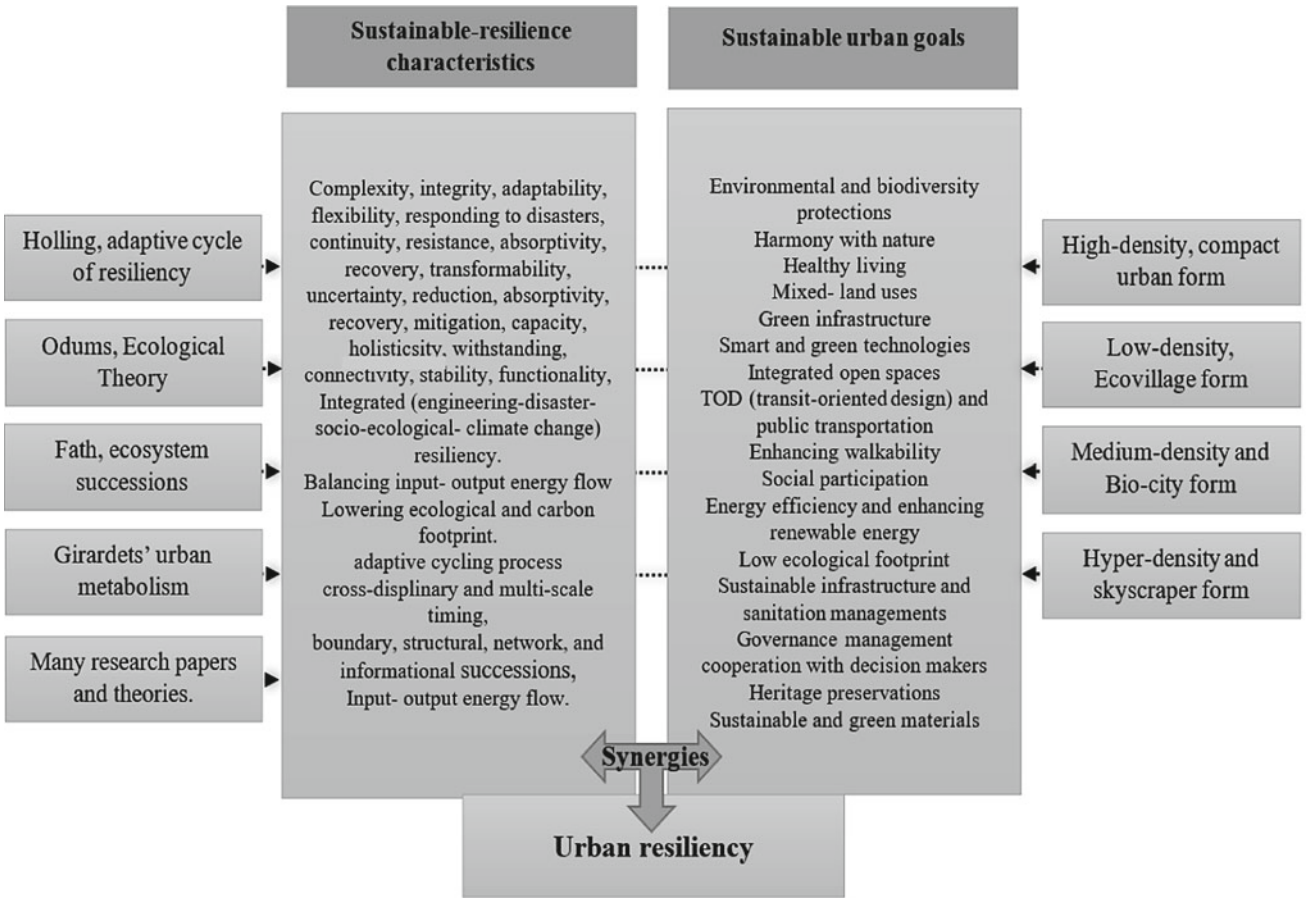



**Fig. 3** Graphical framework of the relationship between resilience and sustainable form strategies

internal and external characteristics that force it to take a different form than the others. So, nature's universal re-organization laws might re-cycle these patterns in a hidden matrix according to the homogeneous or heterogeneous internal sociocultural, economic, eco-environmental, political factors, or external natural or unnatural (wars) shocks, disaster, stress factors. And each city could have several bandalas successions goes and back overtime before moving to another phase of transforming to another level of knowledge and formation as seen in Fig. 4a and b. These adaptive or transformative changes could come in a complex integrative pattern and could have a multiple accumulative (might be not rhythm) scale over time, for various unpredictable successions, as seen in Fig. 4.

## 6 Case Study

### 6.1 Urban Resiliency in Baghdad

Contrary to the previous time periods of Baghdad City, in which urban changes continued for centuries and the fluctuations were slow and relatively few, the researchers found that during the twentieth century, Baghdad, developments and changes in the urban structure accelerated in a radical and legible manner (Majed & ALslik, 2014). According to Al-Musawi (2017) there are eight basic master plans which were prepared during the last 100 years—(1917–2017), of which only three comprehensive developments were adopted in defining the administrative boundaries of Baghdad City, while the rest were implemented in stages and failed to complete the others due to the lack of flexibility in predicting future changes (Al-Musawi, 2017). The research divided these eight master plans into five crucial stages depending on the urban resilience theories phases and successions, explained in detail in Table 1. Each one these stages took practically twenty year trying to reach its stability, except the fourth one which rises almost forty-five years and still stuck in. That is why the fourth stage called stagnation and took widen phase in Fig. 5. As seen, X path is related to time, and with time, the city should take its stability. Y path is related to the relationships which refer to the connectedness of each phase with others. The multiple changes from highly exploitation growth to the

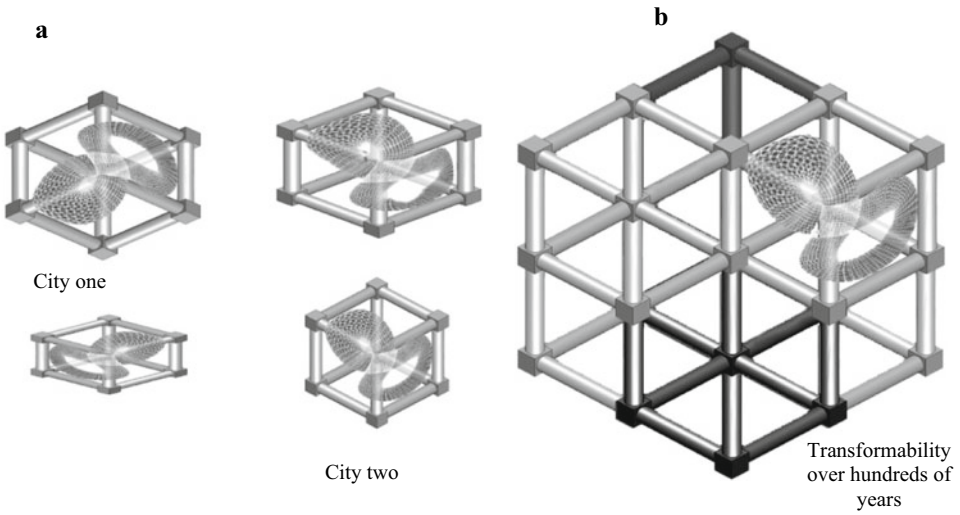



**Fig. 4** Urban structure of the city according to the resilience theories. (Author's drawings)

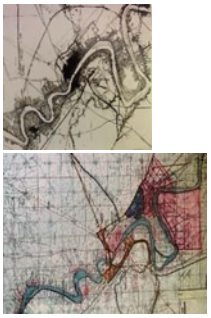
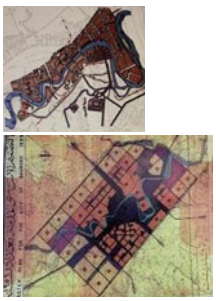
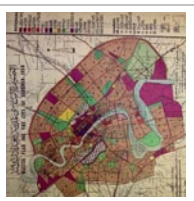
conservation led to the rapid breakdown with a long release in phase four. Z path related to the sources in dynamic goes and back movement. That is why phase five should take enough space because the urban form growth and development in Baghdad experience the same ecosystems' stages, and at this phase, the mistakes should be avoided. Baghdad has its exceptional circumstances that force its adaptive cycle within different successions to take its own formation as seen in Fig. 5. Each phase could possess various names according to the internal and external factors, and these differences came from the complex tribal cultures, believes, and desires which affect its actions. Therefore, the research explains each phase according to its master plans within twenty years.

**The First Phase (1917–1935) The Exploration Phase**: Beginning with the *boundary growth*, which had come from the basic needs of the British Mandate after World War I. The master plan of the German General Goltz considered the first attempt to construct urban roads. The urban fabric of Baghdad consisted of organic streets and alleys with two-floor courtyard houses. Therefore, it represented the phase of exploration and the start of the transition from the traditional and narrow streets to the expansion and the construction of the first street named Khalil Pasha Avenue (Al-Rashid Street today). In 1920, this master plan is followed by the design of G. M. Willson, who directed Baghdad from its traditional wall and suggested reorganizing the city and creating new residential areas. This stage had a little coup of thinking toward a new modern formation, so it had low exploitation. See Fig. 5 and the related Table 1.

**The Second Phase (1936–1955) The Involvement Phase**: The "Brecks plan for Baghdad," is moving to the *structural growth stage*. In addition to the developmental process of the physical structures in numbers, quantities, and component volumes, as a result of gaining the primary energy, the ecological system had a positive feedback approach to product subsystems. This move delivered opportunities to develop the main system and earns more energy. The empirical evidence proved that the structural growth in the city had the same power. However, it took a long time to be accepted by the community, so multiple types of the structure appeared at the same place. Resulting in, the start of road construction and the shift toward iron grid planning had presented the essential transform of an urban mix from the traditional structure into the contemporary one. See Fig. 6 and the related Table 1.

**The Third Phase (1956–1972) The Integration Phase**: The British Miniprio master plan proposal 1956represented the *socio-ecological cycle*, which came with strong steps containing the communication subsystems of the main system through the dynamic transformation activities that lead to increase passes and dynamic recycling. So, this master plan emphasized the necessity of the design flexibility and its ability to change; the radial pattern with a hierarchical system was proposed. It developed into the design of Doxiadis 1959, in which it relied on the theory of geometrical squares named (Ekistics) and network design with separate units and neglected the traditional compact fabric. However, this master plan applied to define the internal division of the city but not the administrative boundaries. This idea of the networked urban system was the start point of the destruction of Baghdad's urban identity (Al-Musawi, 2017; Majed & ALslik, 2014). It was the beginning of the imbalance between the open space and the built structure, neglecting historical characteristics and trying to eliminate heritage. On the other hand, it was an economic flourishing period, many architects went to study in America and Britain, and their return was full of Western ideas, and with expanding the

**Table 1** Baghdad urban resilience phases through 100 years (Al Ani, 2011), (Al- Musawi, 2017), and (Al-Shammari et al. 2019)

| The administrative boundaries of Baghdad City | Phase name Author description | Description of Baghdad City | Urban form growth—change of Baghdad City | Urban resiliency according to Holling | Map representation |
|---|---|---|---|---|---|
| 1917–1935 Goltz master plan Willson master plan | (PH. 1) Phase one: Exploration boundary growth | The urban fabric is compacted with organic narrow streets and alleys with two floors. The start of the transition from the traditional streets to the expansion of urban roads and reorganizing the city and creating new residential areas | High-density, compacted Ottoman courtyard type | Start growth—little exploitation |  |
| 1935–1955 Brecks plan Doxiadis master plan | (PH. 2) Phase two: Involvement structure growth | The start of the streets' network construction and the shift toward iron grid planning represents the main shift of an urban mixed from the traditional structure to the contemporary one | Grid system and some detached urban areas with the courtyard type | Medium exploitation |  |
| 1956–1972 Miniprio master plan | (PH. 3) Phase three: Integration and development structure—networking growth | Start to urban expand, resulting in an imbalance between the open space and the built structure, neglecting historical characteristics and trying to eliminate heritage | Wide streets low-density-detached garden similar to eco-houses | High-exploitation and accumulation, conservation |  |
| 1973–2016 Polservice consulting—Comprehensive JCCF consulting firm | (PH. 4) Phase four: Stagnation networking and information then breakdown | Lacked urban details, lacked in defining the main and the secondary centers, the city lost its green areas, neglected mixed-uses, and the most important thing is the increasing of urban sprawl that led to an acceleration of horizontal expansion | Hybrid structure compact of two storys with detached houses and 4–5 mixed-use building within the same street | Highly exploitation, then conservation, and the rapid breakdown and long release |  |
| 2017–2030 Khatib & Alami | (PH. 5) Phase five: Rejuvenation regeneration growth | Plans and layouts according to the sustainable development goals of preserving the heritage centers, enhancing the recreational areas, re-growing the agricultural areas, creating jobs within the available capabilities and resources, and investing in a reasonable state budget without infrastructure threatening | Hyper-density and skyscrapers type | Reorganization, and persistency |  |

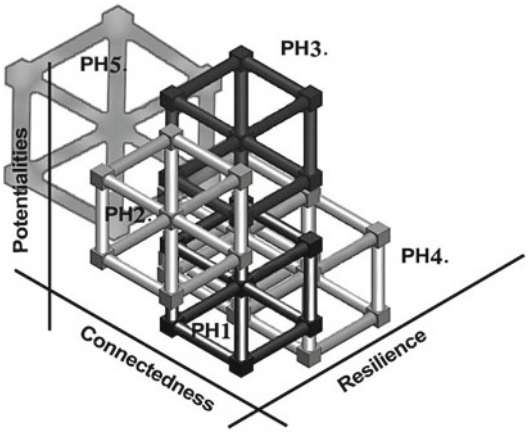



**Fig. 5** Urban structure of Baghdad City, according to the resilience theories, shows a pendulum repetition or frequency of the level of changes within the equivalent period. (Author's analysis)

economy in Baghdad, architects started to cooperate with many abroad companies to build the city. Hence, it would be considered as an integration and development stage with high-exploitation, knowledge accumulation, and a little about conservation. See Fig. 6 and the related Table 1.

**The Fourth Phase (1973–2016) The Information Growth**: This kind is a typical developing in the system behavior from the dissipation and consuming types to the preservative systems more efficient, powerful, integrated, and active. Most of the time, this growth deals with the development of subsystems (other land uses) by increasing their productivity and resiliency with the main system. But in Baghdad, it caused another breakdown and declination point. In the Municipality of Baghdad, specialists realized that the previous master plans did not meet the needs Baghdad, and therefore, the Polish Polservice consulting engineering has been invited in 1965 to work on the comprehensive development plan for Baghdad 2000, and especially after the nationalization of oil in Iraq, new requirements appeared to accelerate growth like studying land uses and absorbing the population density increases. This was produced in 1973, moving toward the vertical construction and adapting the idea of the skyscrapers to accommodate 20% of the population in four administrative circles. Despite the rise in economic prosperity to its peak in the seventies of the last century and the harnessing efforts to provide a comprehensive plan that accommodates all urban changes and the increase in population and housing densities, Polservice master plan lacked in urban details, lacked in defining the main and secondary centers, the city lost green areas, neglected mixed-use amenities, and most importantly the increasing of urban sprawl that led to an acceleration of horizontal expansion at the expense of the scheme (Al-Taif et al., 2014). All these led to the need for preparing a new scheme to avoid past mistakes and reduce urban sprawl. So, the Japanese JCCF consulting firm proposed another plan (the 1990 master plan), which was agreed upon in the eighties, but which was halted in the 1990s due to the Gulf War, that is why it has to be called the stagnation stage that went through multiple changes from highly exploitation growth to the conservation one and rapid breakdown with a long release. See Fig. 6 and the related Table 1.

**The Fifth Phase (2017–2030) The Rejuvenation And Regeneration Growth**: Khatib and Alami consulting master plan—under study since 2007—supposes to be *the regeneration growth*. It is the recorrecting and rising of tracks. The Municipality of Baghdad contracted with the Khatib and

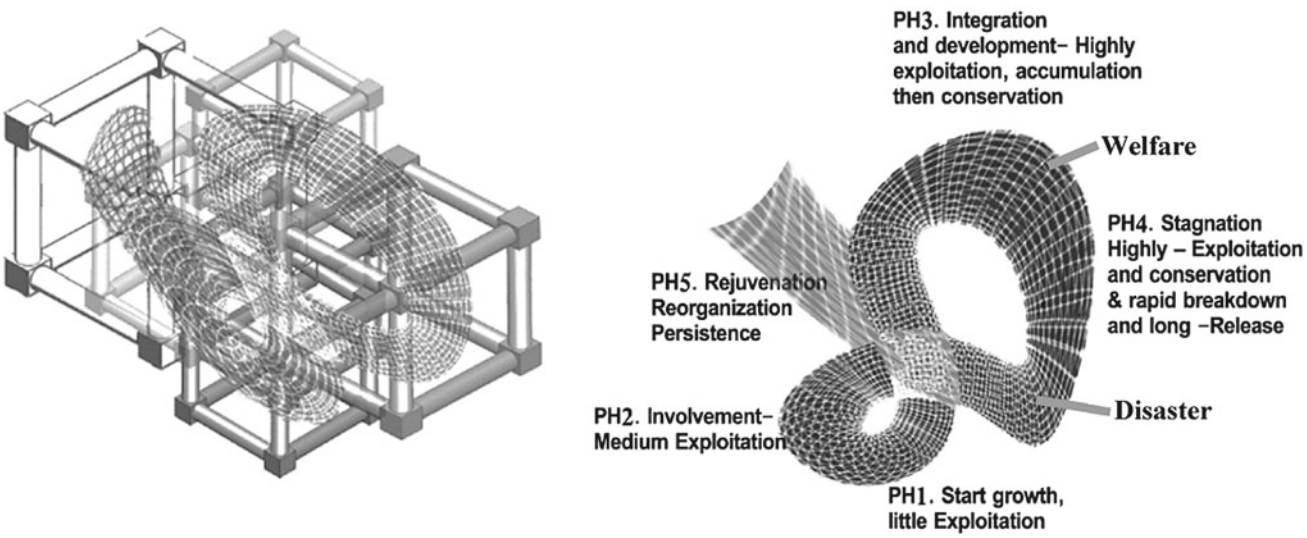



**Fig. 6** Urban structure of Baghdad City, according to the last 100 years' master plans. (Author's analysis)

Alami consulting firm as well as the Japanese MEPEX and PCI in preparing the comprehensive development plan for Baghdad City. It is an avoidance of the mistakes that occurred in the previous stages, in which the city of Baghdad is going according to the sustainable development goals in preserving the heritage centers, enhancing the recreational areas, extending the agricultural areas, creating jobs within the available capabilities and resources, and investing in a reasonable state budget without infrastructure threatening. The comprehensive development plan adopted several alternatives and considered the most convenient alternative to the urban sprawl and problems. It consisted of several urban polycentric urban areas and orientated toward the skyscrapers and vertical compacted housing projects. However, all still on papers straggling between the agreements and the reality. See Fig. 6 and the related Table 1.

### 6.2 Discussion

The comprehensive Polservice plan considered the last approved master plan with clear future vision; what carried on, during the eighties of the twentieth century and after, are proposals. They are delayed and unproven due to the complicated situations and the wars in Iraq. Still, it seems urban changes in Baghdad were interconnected with the phases of resiliency. Each succession has its lines, persistence, precariousness, and panarchy to accept the change and adapt to the new systems. In reversible, each phase of urban growth could have the stages of an adaptive cycle until it reaches stability and moves to the next succession. What happened with the multiple contradictions has been affected the total chain.

After 2003, the conflicts in Iraq negatively affected the urban fabric and its goals to reach sustainability. These conflicts have pendulum changes come and go with political dramatic changes which have adversely affected the integration of urban plans. The result is cumulative, the degradation has become uncontrolled, the over urbanization has spread, and the integration between the traditional area and the whole has lost. Additionally, the specialty of respective large and prestigious construction projects in the early fifties to the eighties has neglected. All these issues led to the missing of connectivity, functionality, and the ability to absorb the multiple disasters faced Iraq. Before 2003, the flexibility is still there, and the city might able to maintain itself; however, many complexities played a significant role to hinder the formation of sustainability toward resiliency.

Socially, hundreds of thousands of people have been displaced from their original neighborhoods to other parts of the city according to their religious faith. With an increased sense of limitations and inequality, it has shattered any sense of social stability. Clear separation and the resulting socioeconomic gaps make restoring urban contact almost impossible, even if public safety is to be restored. Over time, class differences became clear and impacted the changes in the urban social structure.

On the other hand, the inadequate laws regulating building and managing urban planning and the ineffectiveness of the proposed strategic plans led to the deterioration of the built urban environment, the encroachment of land use, the accumulated housing deficits, the informal settlements, the disability of economic development strategy, the insufficient basic services and infrastructure networks, the inadequate road and transportation networks, and the miserly public services and social infrastructure. All these led to the massive loss of the urban balance, the societal harmony, and the healthy living, and drove to the overexploitation and unsustainability (Al Ani, 2011; AL-HASANI, 2012; Al-Saffar, 2017; Banna, 2015).

## 7 Conclusions

There is a tight connection between the meanings and the goals of sustainable and resilient. And, the study concords that the terms “resilience and sustainability” might have the same main characteristics. However, each city has its different phases and successions and should not use the terms interchangeably. Some cities, like Baghdad, might be able to cope with the changes and resilience over time, but it does not relieved the ability to reach sustainability with its urban formation, and it is inaccurate to describe its situation as an urban resilience. For sure, each city provides the properties that distinguish it from others, and day after day, applications and indicators are undertaken to serve some cities and not others. Therefore, there are no ideal steps to follow, and the forces’ factors that extrapolated the urban resilient formation as a sustainable structure are flexible and changeable, which cannot be applied to any city as a typical or prototype resilient theory. Urban resiliency represents a multifunctional, dynamic approach. In which, multiple sustainable synergies with interconnected scales of urban formation could be applied. This result in the adaptive, integrative, flexible urban system is ready to respond to any disturbance changes and recovers itself robustly. However, the research proved some cities, like Baghdad, might be resilience at some levels but fails in others. And, it is misguided to frame the urban formation changes in it with the frame of sustainable synergies. In other words, Baghdad went through multiple adaptive cycles with all the successions of growth in each urban stage to reach resiliency and hybrid system. But this would not sustain with the accumulated pressure. Sustainability means stability over time, and Baghdad in the last one hundred years proved its struggled pendulum resiliency. Whether it is coping with Iraqi identity or not, this

demands several studies to identify the potentialities and the challenges to sustain urban resiliency in Baghdad. Today Baghdad includes a hybrid urban formation which consists of many urban types of density. However, future studies need to identify the socioeconomic impacts and how stressful this system is to reach urban resiliency. Furthermore, extended studies are required to identify which urban type is better in adopting the changes and reach urban resiliency. Still, the conceptual model of resiliency needs data and maybe some simulation programs to read the map practically. However, it is very hard to detect the old data. The map might be there, but the information is limited. These simulations could help in identifying exactly the breakdown points or the growth one related to the urban formation.

Eventually, the research provides a comprehensive analytical base for reading resiliency related to cities urban formation over time and diagnosed the points preventing Baghdad City from reaching the resilience level.

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# An Exploration of the Effects of Urban Block Design on the Outdoor Thermal Environment in Tropical Savannah Climate: Case Study of Nyamirambo Neighborhood of Kigali

Elyse de la Joie Horimbere, Hong Chen, and Mehdi Makvandi

**Abstract**

Urbanization is known to alter the microclimate, thus accelerating the effect of climate change. The built environment can have a positive and negative impact on local microclimates and especially at the neighborhood level. Microclimates at this level are created by items such as building form and geometry, street width, surface material types, soil types, trees, and vegetation types which represent urban block design characteristics. At street level, urban block settings have an impact on the overall air temperature, the surface temperature, the wind distribution, and on the solar radiation, and this will influence the outdoor thermal comfort. In this paper, we explore the impact of urban block design on the microclimate and its impact on the outdoor thermal environment by simulating the microclimate using ENVI-met and by assessing urban thermal comfort using UTCI in a carefully selected urban block fabric of the Nyamirambo neighborhood, which is one of the oldest mixed-used neighborhoods in Kigali presenting a particularly dense urban fabric in the fast-growing city of Kigali. While the region has been experiencing extensively high temperatures during the dry season in the recent past years, this paper tends to highlight urban block design strategies that can help to ease the effects of global warming by providing pedestrians with thermally comfortable conditions. We simulated the microclimate at street level of an urban block model in ENVI-met and analyzed its impact on Ta, Va, MRT, and UTCI at the current state and after introducing urban morphological techniques that have proved to enhance thermal conditions outdoors such as adding trees on the roadside, replacing dark and used concrete pavement with a light concrete pavement with a high albedo, and the creation of a small park to offset the positive impact of cool materials. We also analyzed the results based on the impact of the urban block's building geometry represented by SVF and street orientation. Both strategies proved to have satisfactory results when treated separately. The addition of trees alone led to a reduction of Ta by 3.89 °C and MRT reduction by 1.1 °C at noon. Results of simulations based on SVF and street orientation impact on Ta, and MRT did not show a big difference in this particular urban fabric; however, SVF and street orientation proved to play an important role in the distribution of wind velocity. The best results, however, were obtained in the combination of all the mentioned strategies where the UTCI went from the state of "moderate thermal heat stress" to a state of "no thermal heat stress;" the highest MRT which corresponds to the high-angle sun between 12:00 and 13:00 went from 68 °C to 60.35 °C, especially in the area with added trees and regardless of the street orientation and SVF.

**Keywords**

ENVI-met • Kigali • Microclimate • MRT • Outdoor • Street orientation • SVF • Thermal comfort • Urban block

**Nomenclature**

| | |
|---|---|
| H | Height of buildings |
| SVF | Sky view factor |
| Ta | Air temperature |
| Tmrt | Mean radiant temperature |
| UTCI | Universal thermal climate index |
| Va | Wind speed |
| GHG | Greenhouse gases |
| UHI | Urban heat island |

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## 1 Introduction

Most people live in cities now worldwide which leads to a rather rapid urbanization; rapid urbanization leads to the creation of new cities and expansion of already existing ones which in return leads to an alteration of the microclimate due to the increase of human activities. This forms a very critical environmental situation commonly known as global warming. Higher temperatures in urban areas lead to uncomfortable outdoor areas while at the same time increasing energy use and demand through the use of air conditioning in buildings' interior spaces, creating anthropogenic heat, which, in turn, contributes to the global warming of outdoor air. "We are then faced with a cause and effect loop that needs to stop to improve the conditions of outdoor thermal comfort and so participate in sustainable urban design. As designers, we need to think of an urban design that takes into consideration the impact of our achievements on microclimate" says Achour-Younsi and Kharrat (2016).

According to Wang et al. (2015), "the main factors that contribute to the urban high temperatures are large surface materials (mainly asphalt and concrete) with low albedo and high admittance, reduced vegetation, and permeable surfaces." Mestayer and Anquentin (1994) Oke et al., (1991), add that "The urban microclimate undergoes particular and specific changes such as slowing the wind speed or storage of solar radiation by the construction materials used." "This is a set of parameters, which are mainly due to the building-environment interaction. This complex relationship recently interested researchers and has been studied mainly in the fields of urban climatology. Domain experts agree to recognize the power of regulation of the urban morphology on microclimate parameters;" concluded Achour-Younsi and Kharrat (2016).

That brings us to study the impact of urban morphology at the street level in rapidly expanding cities by taking Kigali city as an example. "Indeed, the street is considered as being the interface between the architectural and urban scale to the extent that it is the common area between the building and the external environment (Ali-Toudert & Mayer, 2006). Therefore, the street is a major element that affects not only the external but also internal microclimate atmosphere," says Achour-Younsi and Kharrat (2016).

At street level, building heights and orientations, spaces between buildings, and plot coverage are variables that can alter solar access, wind speed, and direction. Urban design elements, including vegetation and shading devices, can be used to improve microclimate and comfort conditions (Yahia et al., 2018). Chen et al. (2010) found a linear relationship between SVF and Ta in the warm-humid climate of Hong-Kong, while (Achour-Younsi & Kharrat, 2016) found that the more the H/W ratio decreases, the more comfort decreases.

In the tropical climate of Kigali, climate-responsive urban design has received little attention, although an effort is being made. Strict planning measures, including implementation of the 2013 City Master Plan (Manirakiza, 2014), are in operation.

## 2 Background or Precedence

### 2.1 Study Area

This study was conducted during the hot season (long dry season) in the city of Kigali, Rwanda. "Kigali is at 1°57'S, 30°7'E, 1497 m (4913 ft) and has a tropical wet and dry/savanna climate with a pronounced dry season in the low-sun months, no cold season, and the wet season is in the high-sun months. According to the Holdridge life zone system of bioclimatic classification, Kigali is situated in or near the subtropical dry forest biome. The annual mean temperature is 20.5 °C." (climatemps.com, 2019–2017) During the long dry season, average Ta is about 28.8 °C, average RH is about 58%, while average Va is around 3.4 m/s. In the long and short dry season, temperatures reach 30 °C during the day. Strategic foresight also characterizes Rwanda as a fast warming country, with an increase in the average temperature of between 0.7 °C and 0.9 °C over fifty years. Studies show that the temperature increased with a high frequency of warm days exceeding 30 °C (Strategic Foresight Group, 2013).

Kigali presents various types of urban fabrics. Nyamirambo neighborhood is a sector in Nyarugenge district. It is located in the southwest part of the city of Kigali. The coordinates of the Nyamirambo Sector are: 1°59′37.0``S, 30°02′39.0'E (Latitude: −1.993611; Longitude: 30.044167). It is a mixed residential and commercial sector composed of clustered single-detached buildings (mostly single storied) and a few commercial buildings in the form of mid-rise shape. This is based on observations that revealed that mixed neighborhoods in Kigali are a mixture of planned and informal settlement areas that have progressively merged around a planned site or neighborhoods that resulted from urban transformations, either upgrading or degradation, that affect the initial structure of a planned or an unplanned neighborhood (Baffoe et al., 2020).

Our case study focuses on urban blocks close to the Kigali view hotel in Nyamirambo neighborhood; the area dimensions are 270 × 240 m with an angle of 15°. It is a mixture of single-story buildings with a bunch of mid-rise buildings, little to no vegetation, little to no trees inside properties or on the roadside; a street canopy of 5 m width and a non-built piece of land as portrayed in Fig. 1.

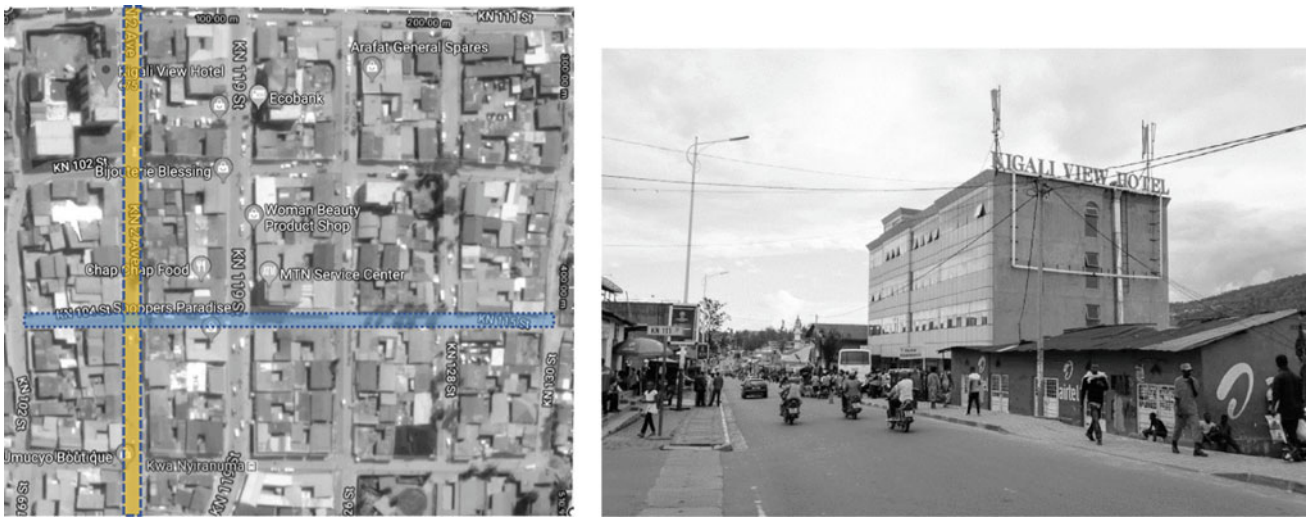


**Fig. 1** (Left) Nyamirambo-street map (Google Maps). Square dot (N–S) and Round dot (E–W). (Right) Nyamirambo-street view (Taken on-site 2018)

## 2.2 Urban Outdoor Thermal Comfort

The outdoor thermal comfort can be classified within fields that began to interest researchers fairly recently. In fact, most scientific research projects regarding thermal comfort are mainly concerned with inside spaces. The issue in understanding the external thermal comfort lies within the multiplicity of factors involved and also the different existing interactions (Achour-Younsi & Kharrat, 2016).

To be effective, the study of thermal comfort is to be conducted by considering its various physical, physiological, and psychological aspects, to put into consideration, the interrelationships between the thermal conditions of the environment, physiological responses, and psychological phenomena (sensation, behavior) (Parsons, 2003). The physical approach of thermal comfort considers the individual as a thermal machine and considers the interactions with the environment in terms of heat exchange. The physiological approach is curious about self-regulatory mechanisms that come into play in a thermal environment, like sweating or shivering. Finally, the psychological approach attempts to see the connection between the physical and physiological variables and sensory results in the individual.

We note that this is a concept that reaches different disciplines. Each specialty has focused on thermal comfort from the precise angle of his discipline. The thermal comfort of an individual depends on the environment first, then her body. Many factors affect the heat flow from the body and therefore the thermal comfort. Researchers have classified these factors into three categories (Auliciems & Szokolay, 1997): climatic factors (air temperature, relative humidity, radiation, and air velocity), personal factors (metabolism, clothing), and contributing factors (acclimation, age, sex…).

The climatic parameters are those that are most considered, since they are the most concrete aspect. Taking into account, the environment requires the quantification of four microclimatic parameters, which are the air temperature (Ta), the mean radiant temperature (Tmrt), the air velocity (Va), and relative humidity (RH). The management of those climate variables simultaneously represents the complexity faced by the designers. They have sought to standardize comfort appreciations by developing thermal comfort indices. Among these, we mention the predicted mean vote (PMV) (Fange, 1970), the physiological equivalent temperature (PET) (Hoeppe, 1999), or the universal thermal climate index (UTCI) (Brode, et al., 2012).

On the other hand, research has also grasped the concept of thermal comfort in trying to understand the influencing factors and might be mastered in urban design (Rizwan et al., 2008). Thus, it was revealed the connection between urban morphology and its direct impact on microclimate variations. Some research has tried to list the most influential morphological indicators on outdoor thermal comfort such as the floor area ratio (FAR), the building coverage ratio (BCR), the H/W ratio, and the SVF (Adolphe, 2001; Ait-Ameur, 2002).

## 2.3 Urban Climate Change Mitigation

The repercussions of climate change will be felt in various ways throughout both natural and human systems in Sub-Saharan Africa. Climate change projections for this region point to a warming trend, particularly in the inland subtropics; frequent occurrence of extreme heat events; increasing aridity; and changes in rainfall—with a