Journal of Human Cognition
2022, VOL. 6, NO. 2, 18-28
DOI: 10.47297/wspjhcWSP2515-469902.20220602

Application and Multi-dimensional Thinking of the 5R Principles in Green Eco-city Construction

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ABSTRACT

Rapid urban development promotes economic development and leads to resource and energy shortage, ecological degradation, environmental pollution, traffic congestion, and other problems. Greening and ecologization have become the trend of urban development. Green eco-city is an ideal model of the livable human city in which people and the environment coexist harmoniously and develop sustainably. The ecology is the primary theoretical basis of a green eco-city, which is positively influenced by the 5R principles. In the present manuscript, we summarised the content and development of the 5R principles and provided some applications of the 5R principles in constructing some eco-cities in various countries from the economy, environment, and society angles. Besides, we discussed the associations of the 5R principles with the spiritual world. It will offer the fundamental theories of the 5R principles for constructing and developing a green eco-city. Although applying the 5R principles in green eco-city construction is still in the practical stage, it has already triggered a multi-faceted reflection on the issue. The 5R principles influence urban development projects worldwide, promoting economic, social, and environmental sustainability, thus leading to a healthier and happier life for people.

KEYWORDS

5R Principles; Green eco-city; Application; Multi-dimensional thinking

1 Introduction

Urban development is a complex social, economic, and environmental phenomenon (Peponi & Morgado, 2020). Nowadays, environmental pollution, energy resource crisis, economic development model, and lifestyle have become significant factors affecting the sustainable development of cities worldwide and an essential obstacle to improving urban residents' quality of life. It has become a global consensus to change production patterns and lifestyles while promoting green development, facing increasingly serious environmental problems.

The resource circular economy is characterized by resource conservation, recycling, and coordinated development with the environment. Promoting cleaner production at the enterprise level and

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developing a circular economy at the social level are important ways to realize the sustainable development of human society. In the 1980s, DuPont Company in the United States summed up the clean production 3R principles (Reduce, Reuse, Recycle). In 2002, the 3R principles were introduced at a conference co-sponsored by the Chinese Academy of Engineering and chemicals company BASF in Germany. In 2005, the 5R principles (Reduce, Reuse, Recycle, Rethink, Repair) were developed based on this Principle at the global "Thinkers Forum". As a new model of international circular economy, the 5R principles are rethinking and repositioning the relationship between human existence and the development of nature and humankind itself.

People have begun to stop blindly pursuing the maximization of economic benefits. Environmental protection and sustainable development are more and more valued by all humankind. The international demand for urban development for greening and ecologization is constantly progressing. In 1971, the United Nations Educational Scientific and Cultural Organisation (UNESCO) first proposed the eco-city concept in its "Man and the Biosphere" program to explore a sustainable path for urban development. In recent years, the concept of Eco-city integrates sustainable development concepts such as green, low-carbon, free carbon, environmental protection, and ecology and applies these concepts to every area of urban development (Hassan & Lee, 2014; Du et al., 2020; Griffiths & Sovacool, 2020; Zhu et al., 2021). Compared with the early concept of Eco-city (Table 1), the concept of Green eco-city also includes green production, green living, green humanities, and other specific aspects (Du et al., 2020). It aims to establish and improve the urban economic development and enterprise clean production models, maintain a benign urban ecological environment, actively advocate and cultivate a green lifestyle, and ultimately improve people's quality of life.

As early as 1992, Dominsk had proposed a three-step model for eco-city development, namely Reduce, Reuse and Recycle (Dominsk, 1992). This is considered an early practice of the 3R principle to guide the construction of eco-cities. Drangert suggested that reusing and recycling water and nutrients and reducing harmful chemicals in consumer products facilitate treatment would help develop resource-smart cities (Drangert, 2021). Applying the 5R principles in green eco-city construction is in an experimental and constant development stage. In this article, we introduced the content of the 5R principles and analyzed some positive practices of the 5R principles in building green eco-cities worldwide from environmental, economic, and social perspectives. We hope to inspire people to create a healthy, harmonious urban environment with a green eco-city by considering the 5R principles in many aspects.

Table 1. Comparison of eco-city with green eco-city

Items	Early eco-city	Green eco-city
Proposed	1971	Proposed in 1990; constantly updated
Theoretical basis	Ecology, sustainable development theory	Ecology, sustainable development theory, systematics, urbanology, sociology
Application	Urban planning, resource and energy utilization, comprehensive waste utilization, clean production	Urban economic development, clean production, low carbon, green lifestyle, cultural and spiritual world construction, etc
Goals	Harmonious coexistence between humans and nature	Ecologization of urban economic, social and environmental systems, Harmonious coexistence between human, nature, society, and economy
Status	Starting and exploring	Concept advocating, the development trend of future urban
Roles of the 5R principles	Guiding clean production and circular economy	Guiding the construction of green eco-cities in multi-direction

Referred literature (Gordon, 1990; Xie, 2011; Du et al., 2020).

2 Conceptual framework

2.1 The 5R principles

The specific contents of the circular economy 5R principles include:

(a) Reduce Principle: The input side of the production process requires saving resources and reducing pollution from the source of economic activities. Common methods include reducing the number of raw materials and energy used in production, simplifying the process, miniaturizing, lightening, and simplifying the product, thereby reducing waste liquids, waste gases, waste residues, and even waste reaching zero emissions (Dong, 2013; He et al., 2007; Hassan and Lee, 2014).

(b) Reuse principle: Its requirements extend the life cycle of products and services for the production process. For example, the initial form of reusing the packaging containers resist disposable supplies, thus lowering energy consumption, reducing costs, and minimizing pollution.

(c) Recycle Principle: For the output side of the production process, it requires transforming products that have completed their life circles to useable resources, including primary recycling (similar products produced from the waste) and secondary recycling (wastes transfer into other products), effectively solving resource resources, reducing pollution, and cutting costs.

(d) Rethink Principle: For the reflection and innovation for the old economic theory, it requires rethinking the recycling process, including capital and labor, and resources to fully enhance resource-saving potential. Based on this principle, the new economic theory emphasizes that production consumes resources and conserves existing resources. This principle applies to the entire resource use process, including design, extraction, production, and consumption of products. It also demands policymakers to incentivize conservation by establishing policies and monitoring the achievements.

(e) Repair Principle: A new development concept to restore the ecological system has been established. Based on the above four principles, the producing side (e.g., factories) minimizes the negative environmental impacts and repair the damaged environment to maintain ecological balance.

Up to now, the circular economy 5R principle is widely used in the integrated use of various polutants generated in industry, agriculture, life, energy conservation, and emission reduction (He et al., 2007; Cai et al., 2019; Sharma et al., 2020). At the same time, society has advocated and implemented waste separation, recycling and integrated use to realize urban and ecological co-development (Faraca et al., 2019).

2.2 Supplement of the 5R principles

The 5R principles of circular economy are the most common and advanced production concept at present and are also evolving. 5R principles are adapted to the specific situation and have various expressions. For example, another 5R principles version is based on the 3R principles complemented by Regeneration and Rejection. The Regeneration Principle emphasizes using renewable natural resources products (such as paper) and renewable materials (such as renewable plastics) for production as far as possible to save resources and reduce pollution. The Rejection Principle is to refuse the use of irreplaceable, non-recyclable, non-renewable, non-reusable, toxic, and polluting raw materials in the production process. It also includes refusing to buy over-packaged items and wild animals and buying wild animal fur products (Dong, 2013). Facing the trend of green lifestyle, the international community has extended the 5R principles to include the Reevaluate principle and the Rescue principle. The Reevaluate principle refers to substituting environmentally friendly green products for highly polluting and consumable products. Priority should be given to products with green markings when consuming. The Rescue principle encourages species rescue, refuses to eat and use wild animal products, and stops poaching and trading wild animals. World Skills International's sustainable development strategy also lists the 5R principles: Reduce, Recycle, Reuse, Reformat, and Rege-

nerate. The 5R principles are also described as Reduce, Recycle, Reuse, Redistribution, and Recultivation (Zhang, 2017); or Reduce, Recycle, Relocate, Replace and Restore (Li et al., 2008). These components supplement, enrich, and develop the 5R principles of environmental protection.

3 Empirical evidence: The application and guidance of the 5R principles in different fields of green eco-cities

3.1 The 5R Principles and economic development

As developing countries put their survival issues first, prioritizing economic development can easily lead to environmental pollution. Developed countries now tend to build a green economy, known as a circular economy. The growth model of the circular economy is based on circular production. Energy conservation and cleaner production are common ways to achieve a green economy, including source management, process management, end-of-pipe treatment, and others (Kumar et al., 2020).

In exploiting environmental resources, human beings inevitably cause damage to the environment. But modern civilization needs the maximization of the economy and the maximization of civilization. Maximizing civilization means developing the economy while protecting the ecology. We use the economic civilization index (Iec) to measure the degree of human economic civilization, which is proportional to the amount of human economic production (represented by Gross Domestic Product (GDP)) and inversely proportional to the amount of environmental damage (represented by ED), expressed as follows (Dong, 2013).

$$Iec = GDP / ED \quad [1]$$

According to formula 1, we can analyze the changes in the index of economic civilization under different economic development methods. When GDP increases and ED increases to the same extent, the value of Iec will remain the same. Production output will increase simultaneously with pollution. This economic production activity has been backward and will slow down the economic civilization of human beings.

The value of Iec increases when the GDP increases and the ED remains stable. This indicates that the economy can grow with pollution control but only ensure that the environment is not further damaged. This economic production activity improves the economic civilization and controls the total amount of pollution to some degree.

When GDP increases and ED decreases, the Iec value increases significantly, indicating that economic growth is accompanied by pollution reduction and environmental improvement. Economic production can significantly improve human civilization and realize circular economy and ecological civilization. One of the main tasks of environmental science is to reduce ED while increasing GDP through new processes, technologies, and methods. Meng et al. expound on an urban ecological transition strategy with higher economic output without ecological degradation (Meng et al., 2021). Qian et al. analyzed the data of 274 prefecture-level cities in China from 2004 to 2017. They pointed out that reducing per unit GDP energy consumption and lowering waste emissions are key ways for smart cities to promote green economic growth (Qian et al., 2021). It is similar to the economic civilization index (Iec) proposed in this study. These provide a useful way to implement the economic development model of ecological cities. The civilization of human production activities can be divided into three stages: one is to increase production and reduce pollution, another is to increase production without increasing pollution, and the third is to increase production and reduce pollution. Increasing production and reducing pollution simultaneously is the best economic development model and the highest level of sustainable development.

3.2 The 5R principles and environment

Cleaner production technology can reduce output waste at the source. It enables effective environmental protection by shifting from end-of-pipe management to pre-production and even full-production waste control. In this process, industry and agriculture can use resources more efficiently, thus saving energy while reducing industrial and agricultural waste and domestic waste emissions. Guided by the 5R principles, many companies have transformed zero-emission production and strive to achieve 100% resourcefulness of waste to reduce resource waste and pollution emissions (Dost et al., 2019; Sadala et al., 2019). Also, many new technologies have been promoted, including cleaner production technologies, integrated energy use technologies, alternative technologies, waste recovery and recycling technologies, and low-carbon technologies, to achieve environmentally sustainable development (Niakolas et al., 2016; Dost et al., 2019; Faraca et al., 2019; Sadala et al., 2019; Yang et al., 2019). Based on the 5R principles (Reduce, Reuse, Recycle, Recover, and Restore), the waste-to-energy nexus is considered a paradigm for the sustainable development of the eco-friendly city (Sharma et al., 2020). Urban bicycle is also a novel closing loop toward reusing and recycling materials in technical and biological cycles to reduce waste generation in an urban ecosystem (Venkata Mohan et al., 2020). Photovoltaic solar panels used on rooftop areas in three medium-sized cities in Peru have achieved self-sufficiency in electricity and reduced greenhouse gas emissions (Bazán et al., 2018), which meet the Reduce principle and benefit low-carbon city growth.

3.3 The 5R principles and society

A green eco-city can be seen as a new way of social life. From a certain perspective, the 5R principles advocate a green lifestyle that encompasses all aspects of life, including clothing, food, housing, and transportation, such as frugal, green, low-carbon, civilized, and healthy. It enlightens all aspects of social life.

(a) Insight into the clothing

The consumption of resources, environmental damage, and adverse effects on human beings are thoroughly considered from the beginning of clothing design. Whether it is fabrics, accessories, decorations, or clothing packaging materials, biodegradable and recyclable materials should be used as much as possible in clothing production. Producing and choosing clothes under the 5R principles could meet consumer needs for healthy, safe, and green dressing (Xiao & Sun, 2019).

(b) Insight into the diet

The food utilization rate is reduced when the body ' s energy intake exceeds the energy needs for human activities. Meanwhile, redundant energy in the body could cause diseases such as obesity, hyperlipidemia, and hyperglycemia. Low utilization rates of resources and energy result in resources not being used to their full potential and are not eco-friendly. In addition, it is even less in line with the 5R principles of reduction with food waste.

(c) Insight into housing

Large houses can be wasteful in resources, energy, and space. Heating, air conditioning, and lighting will consume more fuel and electricity and waste more labour and material resources for large houses' sanitation and cleaning, room equipment, and property management. A nice living environment should be moderate in size and easy to live in, accompanied by reasonable structure, environmentally friendly materials, good greening and comprehensive support. Conversely, if economic prosperity is evaluated on luxury, it would harm the earth's resources. Green building includes reducing indoor air pollution sources and improving energy efficiency. Reducing fossil fuel consumption and using environmentally friendly and energy-efficient materials is excellent for developing green buildings (Rajabi et al., 2021) because of reducing indoor air pollutants and enhancing energy efficiency.

(d) Insight on transportation

Unnecessary car use and traffic congestion can waste time and energy. 5Rs reflect the choice to take non-motorized vehicles (walking or biking) or to take green public transportation (green vehicles such as electric or methanol and natural gas-fueled vehicles). A study from Pakistan concluded that introducing green vehicles and a green transportation system is imperative for a country's long-term sustainable development (Shouket et al., 2019).

In addition, the 5R principles have many implications for various aspects of daily life, such as promoting resource conservation (e.g., water, paper, energy, electricity, CFLs, paper) and promoting low-carbon living. In green communities, management and residents must separate and recycle waste, supporting recycling resources and energy. The government can also inspire the 5R principles to promote an all-encompassing culture of conservation, encouraging reuse and multiple uses of goods. Furthermore, policymakers can applicate the 5R principles in daily life, such as encouraging green consumption, purchasing low-pollution and low-consumption green products, using as few disposable items as possible, and encouraging reducing material consumption and pollution emissions. Citizens who are more environmentally conscious can live in harmony with nature and the creatures.

In short, the 5R principles are reflected in all aspects of daily life. Human beings should deeply understand and apply the 5R principles to maintain the home they depend on.

3.4. The 5R principles and the spiritual world

The 5R principles positively guide physical and spiritual worlds (Dong, 2013). Although there is no factual and scientific basis for the relationship between the 5R principles and the spiritual world, it could likewise be helpful for green eco-city planning. That is important to examine and apply the 5R environmental protection principles wisely to prevent spiritual pollution and attention, reflection, and improvement of the human spiritual world.

(a) Reduce Principle: Reducing the desire for material things, unnecessary spiritual burdens, and pressure; Reducing negative emotions and pursuing simple happy life.

(b) Reuse principle: Maintaining the progressive nature of human civilization requires constant inheritance, advocacy, and continuous learning of developed and advanced civilizations.

(c) Recycle Principle: People need frequent repetition of lifestyles conducive to protecting their mental health. This repetition reinforces memory and forms habits. Repetition of rules and laws can regulate behaviour, protect people's rights, and facilitate their lives.

(d) Regeneration Principle: In comparison with the principle of reuse, the principle of regeneration advocates inheriting and developing progressive ideas passed down by human society to allow the crystallization of human civilization by bringing forth new ideas.

(e) Reject Principle: One requirement for building spiritual civilization is to promote truth, goodness, and beauty while rejecting language or behavior that is anti-civilization, rude, anti-intellectual, unhealthy, or causes spiritual pollution. Reasonable rejection helps maintain spiritual health, creates a better social atmosphere, and constitutes a good cycle of civilization.

4. Green eco-city construction and the 5R principles

The 5R principles have shown a new guiding role and application potential for promoting green eco-city development in the face of the challenges posed by the "urbanization-economy-environment" imbalance.

Countries worldwide have accumulated many successful experiences developing green eco-cities (Table 2). For example, the eco-city of New York in the United States has achieved remarkable results in energy conservation and low-carbon development by developing energy-saving green

buildings, promoting clean fuel and renewable energy, and developing smart public transport systems. Its urban construction also considers economic development, environmental protection, and livability. Indicators such as the proportion of green belts and the number of public facilities are used to reflect the vitality of social interaction, which can improve the living environment (Zhang et al., 2018), fully reflecting the 5R principles (Reduce, Rethink, Repair). Kitakyushu is recognized as the most mature eco-city demonstration project in Japan, which has improved urban shrinkage and environmental degradation by incorporating a circular and low-carbon economy into urban development planning (Ortiz-Moya, 2020). This project promoted energy-saving facilities, waste recycling and comprehensive utilization, used circulating water, and built ecological buildings. These measures comply with the 5R principles like Reduce, Reuse and Recycle. The Tianjin Eco-city adopts the three-level housing model of "eco-community-ecological zone", which sufficiently considers the bearing capacity of resources and environment, focuses on the development of green industries with low energy consumption, no pollution, and high added value, uses renewable energy (solar energy, geothermal energy, wind energy, and biomass energy) in multiple sources, and promotes waste separation and resource utilization (Geroe, 2017). Reduce, Reuse and Recycle principles were fully applied in constructing this eco-city.

Table 2. The cases of association of eco-city with the 5R principles

Eco-city	Construction characteristics	5R principles
New York in the United States	Energy-saving, low carbon, green, intelligent transportation system, livable	Reduce, Rethink, Repair
Kitakyushu in Japan	Energy-saving, waste recycling, and comprehensive utilization; using recycled water, ecological building	Reduce, Reuse, Recycle
Sino-Singapore Tianjin Eco-City in China	Green industry, use of renewable energy, waste classification, and resource utilization	Reduce, Reuse, Recycle
Los Angeles eco-city in the United States	Protecting historical and cultural sites, endangered species and forests, and green spaces	Repair, Rejection

Referred literature (Geroe, 2017; Zhang et al., 2018; Chen, 2019; Ortiz-Moya, 2020).

Of note, in the process of the construction of the Los Angeles eco-city in the United States, the remarkable achievements were the protection of historical and cultural relics, endangered species, and forest green space (Chen, 2019), which further reflected the elements of cultural protection in green eco-city. Simultaneously, they conformed to the principles of restoration and rejection in the 5R principles. Besides, some typical eco-cities or eco-communities, such as Malmo in Sweden, Vauban in Germany, and Masdar in the United Arab Emirates, had achieved resource conservation and material recycling and accumulated successful experience in constructing green eco-cities (Li et al., 2018).

Nowadays, the construction of green eco-cities in various countries is still in the exploration stage, and each country has its own characteristics. Most European and American countries adopt the bottom-up construction model. Their construction emphasizes government advocacy, market promotion, and extensive public participation. This problem-oriented eco-city construction model in European and American countries emphasizes operability and standards (Li B & Li X, 2016). In contrast, the construction of eco-cities in China is a goal-oriented model, led by the government with limited citizen participation. In 2012, for example, 280 cities in China-proposed "eco-city" construction goals, and government policies guided and promoted the construction of eco-cities (Li et al., 2018).

In 1998, Wheeler proposed nine indicators to assess green eco-cities: effective land use, efficient resource utilization, low pollutant emission rates, protection of natural systems, good living and residential environments, healthy social ecology, sustainable economy, social participation, cultural

preservation, and green transportation (Wheeler, 1998). These indicators have been recognized worldwide. They conform to the connotation of the 5R principles and reflect the green humanistic spirit of putting people first and improving the living environment and quality of life. In the specific implementation process of different countries, there are various focuses on these indicators (Zhao et al., 2012). For example, Sweden's Hammarby Eco-City focused on efficient land use, green travel, full use of renewable energy, water-saving and sewage treatment, and waste classification and recycling (Zhao et al., 2012). China's Green Ecological Urban Area Evaluation Standard (GB/T 51255-2017) mainly includes eight indicators, including land use, ecological environment, green building, resources and carbon emissions, green transportation, information management, industry and economy, and humanities. The metric systems of different eco-cities are different, and the components, structural levels, and quantities of the metrics are also distinctive. However, their ultimate goal is the same, that is to achieve a harmonious coexistence between nature and human beings through a composite system of "nature-society-economy." This is consistent with the connotation of the 5R principles.

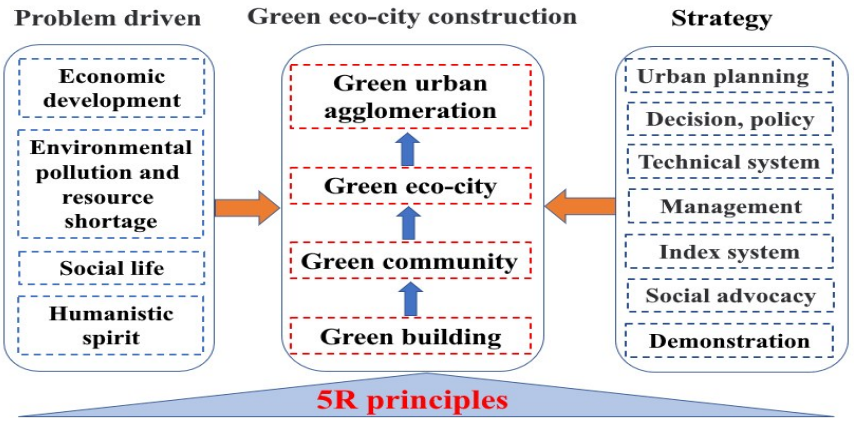
Countries are encouraging the exploration of green eco-cities planning methods and construction models. For example, Ye introduced sustainable urban planning from energy, water, waste, transportation, ecosystem, and social and economic development in the Dongtan eco-city project on Chongming Island, Shanghai (Ye, 2008). As shown in Figure 1, driven by issues in the economy, environmental pollution, and energy shortage, social life, humanistic spirit, the construction modes of green eco-city can be classified from small to large as follow: green buildings, green communities, green ecological parks, green cities, and green city agglomeration. In constructing green eco-cities, several support aspects are needed: urban planning, decision-making policy, technical system, management system, index system, social advocacy, demonstration, and promotion (Chen et al., 2020; Du et al., 2020). People should promptly summarize and promote mature and applicable technologies to achieve a point-to-point scale replication effect. A benignly developing green eco-city should be diversified and replicable. Facts have proved that Reduce, Reuse, and Recycle principles in the 5R principles play a positive guiding role in the green eco-city planning and technology system. Other elements of the 5R principles (such as Rethinking, Reevaluation, Regeneration, Rejection) also actively guide the green eco-city in terms of lifestyle, culture and social construction.

Making full use of the 5R principles to build green eco-cities is a new topic to be considered. We believe that the 5R principles promote more innovative and sustainable technologies to combat urban environmental pollution, build green eco-cities, and help people develop green, low-carbon, and sustainable lifestyles through advocacy and regulations.

5. Conclusions

The 5R principles can protect the environment and regulate the economy, promoting the succession and development of human civilization. Establishing a green ecological city under the 5R principles can promote the harmonious development of the economy, society, and environment and solve the contradiction between urbanization and environmental protection. People can achieve a healthier and happier life by building a resource-saving and environment-friendly society and constructing a green, low-carbon circulation development model and lifestyle. People will be inspired by green eco-city construction and 5R principles in more aspects in the future and further improve society, environment, and life.

Figure 1. Building green eco-cities based on the 5R principles



Disclosure statement

No potential conflict of interest was reported.

Funding

This work was supported by the Hundred Talents Program of Shanxi Province in China (2017-7).

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