Article Title:

Smart city and resilient city: differences and connections

Article Type:

Overview

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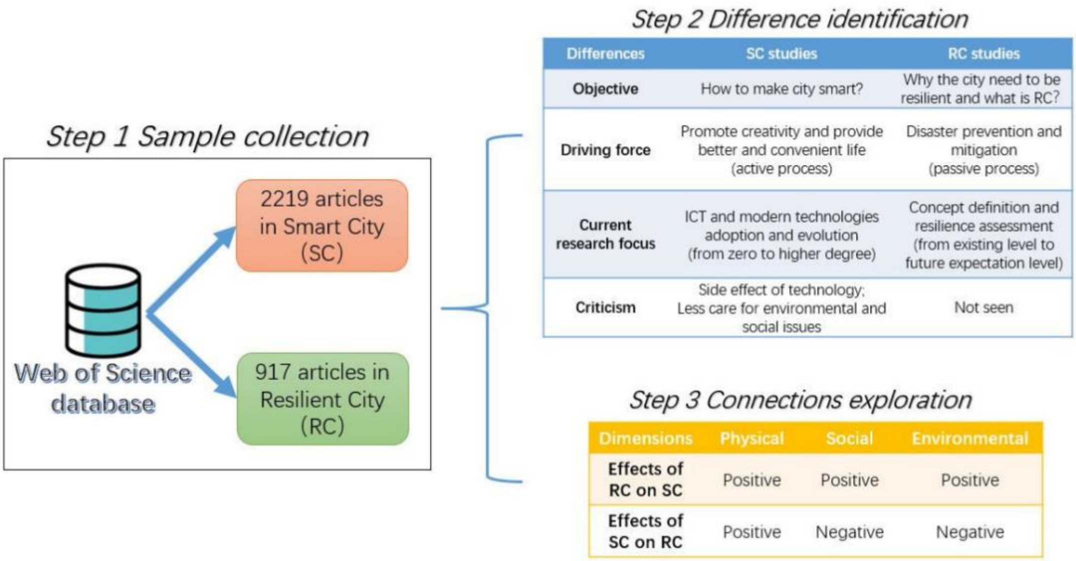
Abstract

Smart city (SC) and resilient city (RC) have been studied and practiced over the years in terms of the increasing urban problems and disasters. However, there is a large overlap between their meanings and relationships. With an increasingly concern for both SC and RC in urban development and hazard mitigation, a review was conducted to explore the differences and connections between SC and RC with scientometric analysis. There are far more literatures about SC than RC, and very few papers discuss SC and RC together. The research trend, category and hotspots from research clusters are illustrated and compared. Major differences are discussed from their objectives, driving force, current research focus and criticism. The literatures both related to SC and RC are used to explore their connections, which are very limited. The results revealed that the RC's impact on SC are positive from physical, social and environmental aspects, while SC's impacts on RC could be both positive and negative from the above three aspects. It is indicated that SC and RC are both important for urban planning and can be complementary to each other through proper design and governance, which grows the need for building a resilient smart city (RSC).

Keywords: smart city; resilient city; scientometric analysis; co-citation analysis; resilient smart city

Graphical/Visual Abstract and Caption



An overview of differences and connections between smart city and resilient city

1. INTRODUCTION

The process of urbanization has resulted in varying degrees of impacts on the city's economy, resource utilization, quality of life, time costs, and sustainable development (Eremia et al., 2017; Macke et al., 2018). With urbanization and an increasing population (United Nations, 2014), the symptoms of cities are increasingly prominent, such as energy shortages, air pollution, and waste management (Zhu et al., 2019). In this circumstance, smart city (SC) is hoping to use information and communication technologies (ICT) and other modern technologies to solve these problems and improve the way city works (Batty et al., 2012). Great efforts and attempts are being made to make the city smarter around the world. For example, San Diego in United States installed 3200 smart sensors to optimize traffic and parking and improve public safety, environmental awareness and overall livability for the city and its people (Montgomery, 2019). Vancouver, Canada has adopted the Smart City 3.0 model by involving 30,000 of its citizens in the co-creation of the Vancouver Greenest City 2020 Action Plan (City of Vancouver, 2015). To date, more than 1,000 smart city pilot projects are ready for or under construction worldwide and China is home to around 500 of them, covering both large and small cities, according to Deloitte's report (Chou et al., 2018).

The researches in SC are also in full swing. Although there is still a lack of shared and sound definition of SC (Zheng et al., 2020), technology and people are two of the main concerns in the SC concept (Neirotti et al., 2014; Su et al., 2017). Modern technologies such as the Internet of Things (IoT), big data and fog computing are being explored and tested to be better applied in SC practice (Han & Hawken, 2018; Zanella et al., 2014). People, education, learning and knowledge are also considered to have a central role in SC to improve the productivity and quality of life (Albino et al., 2015; Lytras & Visvizi, 2018). With further research, the challenges and future of SC are getting more and more attention, emphasizing that technology is not a panacea (Boulos et al., 2015). Other factors related to green and sustainable development, such as the environmental protection and public security in SC construction, are equally important in creating happier and healthier cities (Yigitcanlar et al., 2019).

During SC's practice and research over the last twenty years, the world has also suffered from unprecedented global climate change. Rapid urban development also makes cities vulnerable to natural hazards. Meteorological disasters occur frequently, and catastrophic disasters like floods, earthquake, and hurricane have caused enormous losses to the city and human beings (Meerow et al., 2018). In addition to natural disasters, impacts from human behaviors have also caused serious damage to the city, such as terrorist attacks. Not to mention the sudden virus (COVID-19) that brought huge risks to humans, affecting more than 180 countries and regions (World Health Organization, 2020). Wuhan, a modern and smart city with more than 11 million populations in China, was closed due to this great urban crisis (Zhou et al., 2020). As a result, with the growing vulnerability of cities (Szewrański et al., 2018), the rising social development uncertainties and increasing awareness of risks among people, building a resilient city (RC) has also gradually been valued by major cities around the world. RC is considered as the city's ability to absorb, adapt and transform external pressures and ensure urban safety in the event of any crisis, hazards, or disasters (Rus et al., 2018). Smart metropolises like New York, London and Amsterdam also have their RC planning to deal with natural hazards and social attacks. There are also increasing numbers of research related to RC studies, including concept definition, evaluation framework and improvement suggestions (Campbell et al., 2019; Meerow et al., 2016; Mehmood, 2016).

Obviously, both SC and RC have attracted more and more attention from researchers and city decision-makers. Several reviews have already summarized the relevant studies in SC and RC respectively. For example, Ruhlandt (2018) reviewed the governance of SC, Silva et al. (2018) reviewed the trends, architectures, components and challenges for SC, Soomro et al.(2019) reviewed the big data analytics adopted in SC, and Zheng et al. (2020) reviewed and summarized the structure and evolution of studies on SC between 1990 to 2019. As for RC, Meerow et al.(2016) reviewed its definition and Rus et al.(2018) reviewed its assessment frameworks and methods. Some researchers also reviewed the resilience in a variety of disaster scenarios, such as floods and earthquakes (McClymont et al., 2019).

However, these current reviews and studies on SC and RC are very fragmented and separated, with few research studies considering SC and RC together. There is an overlap between the meaning of SC and RC in dealing with urban issues (Arafah & Winarso, 2017), which could undermine both concepts. Questions like do they have the same meaning to create better city and better life, do they share the same path or will they interfere with each other, and does it matter at all which one is chosen, are still waiting for answers. In order to fill this gap, the aim of this study is to conduct a thorough literature review to identify the differences and connections between SC and RC. Such a review may help to identify the trends and relationships between SC and RC, as well as finding research gaps and directions for future studies in these fields. It aims to provide clearly understanding of the SC and RC concept, to find their possible connections and to support further studies and practices in SC and RC.

This paper is organized as follows. The research methodology is set out in Section 2. The differences between SC and RC in research trend, category and clusters are identified in Section 3. Section 4 explores the connections between SC and RC with articles covering both terms. The suggestions and conclusions are provided in Section 5 and 6.

2. METHODOLOGY

A three-step scientometric analysis is adopted in this paper to explore the differences and connections between SC and RC. Scientometric analysis is used to objectively map the scientific knowledge area, which has been widely and effectively used for the reviews in different domains, such as architecture, engineering, and artificial intelligence (Darko et al., 2020; Liu et al., 2019; Pilkington & Meredith, 2009). The method used in the paper helps to find the scientific and empirical results of the SC and RC studies. The details of the steps are shown in Figure 1. Step 1 is to select the literature sample from proper database with search strategy. Step 2 is to identify the differences between SC and RC with comparisons from their research trend, category and clusters. Last, the articles related to both SC and RC are selected for connections exploration in Step 3.

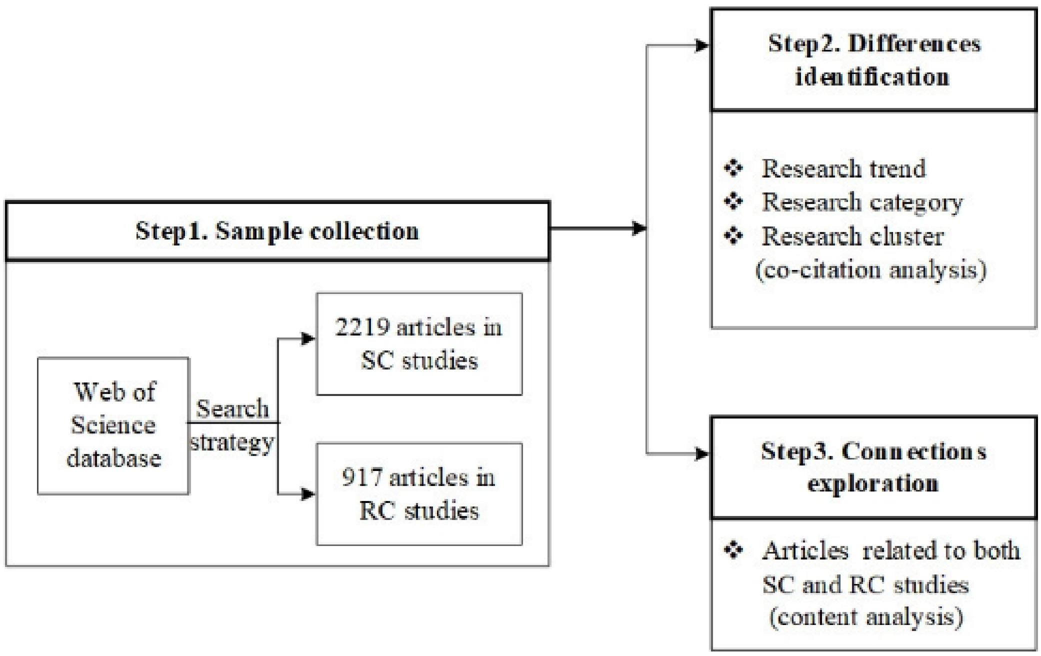


FIGURE 1 Methodology flowchart

2.1 Sample selection

In order to identify the relevant studies and minimize the exclusion of the most important and relevant publications in the field, Web of Science (WoS) is chosen as the appropriate search engine. As a traditional and comprehensive database for citation analysis, WoS can support longer periods of citation analysis and higher-quality scholarly data compared to other search engines, such as Scopus, and Engineering Village (Zheng et al., 2020). Only articles in English are considered. Till April 2020, the search term “smart* city OR urban smart*” in the title results in 2219 English articles, while the search term “resilien* city OR urban resilien*” results in 917 English articles. These articles are collected and used as literature samples for follow-up analysis.

2.2 Differences identification

The articles selected above are used to identify the differences between SC and RC. First, the numbers of articles published each year are used to compare the research trends in SC and RC. Then, the categories of the articles in WoS are used to compare the SC and RC research domain. Next, the research clusters for SC and RC are identified respectively by co-citation analysis, which helps to find hotspots for SC and RC studies. Co-citation analysis is one of the quantitative techniques capable of enhancing the visual and logic understanding of systematic review findings by clustering and measuring the performance and pertinence of papers with mathematical modeling and algorithms (Hu et al., 2019). It is also considered to be a common research method for explaining science-based production and research hotspots for a given topic (Gao & Ruan, 2018). This co-citation network is conducted with the help of *CiteSpace*, which is a versatile toolkit designed for visualizing patterns and trends in scientific literature (Chen et al., 2010). Last, according to the in-depth cluster hotspots analysis, main differences in the research priorities of SC and RC can be summarized and discussed.

2.3 Connections exploration

Articles related to both SC and RC are chosen for the connection exploration. The previous sample articles are first screened by manually reading their title, keywords, and abstract. Then, these articles discussed in both SC and RC are selected for the whole content analysis. Last, the research connections between SC and RC are summarized and discussed qualitatively. Thus, possible research suggestions can be proposed at the end of the paper for academics to continue their work on SC and RC in future directions.

3. DIFFERENCES BETWEEN SC AND RC

In this section, research trend, research category and research clusters form co-citation analysis are used to represent the evolution of the differences between the SC and the RC studies.

3.1 Differences in research trend

Publication year distribution of articles in SC and RC is used to explore their research trend as shown in Figure 2. Although the amount of publications in SC is far more than RC, the first RC-related article (Thompson, 1978) is published six years earlier than SC (Rossi, 1984). This is echoed with the fact that the concept of resilience was proposed by Holling (1973), and was gradually introduced into urban research field. While, the concept of SC attracted people's attention in the smart movement of the 1990s and experienced the evolution from digital to intelligence then to smart (Zheng et al., 2020).

There are 2219 SC papers over the period compared to 917 RC papers. Since the search was conducted in April 2020, there is a decline at the end of the period. Although both have enjoyed steady development in the first 30 years and have begun to increase since 2010, the development trend is quite different. The publications in SC have witnessed an extremely rapid development in the past 10 years, with more than 600 publications in 2019 showing an ever-increasing trend. While the publications in RC started to increase dramatically from 2015 to the peak in 2017, and declined to a steady level afterwards. The development of RC is relatively slow and progressive. The studies in SC received more attention and developed faster than RC.

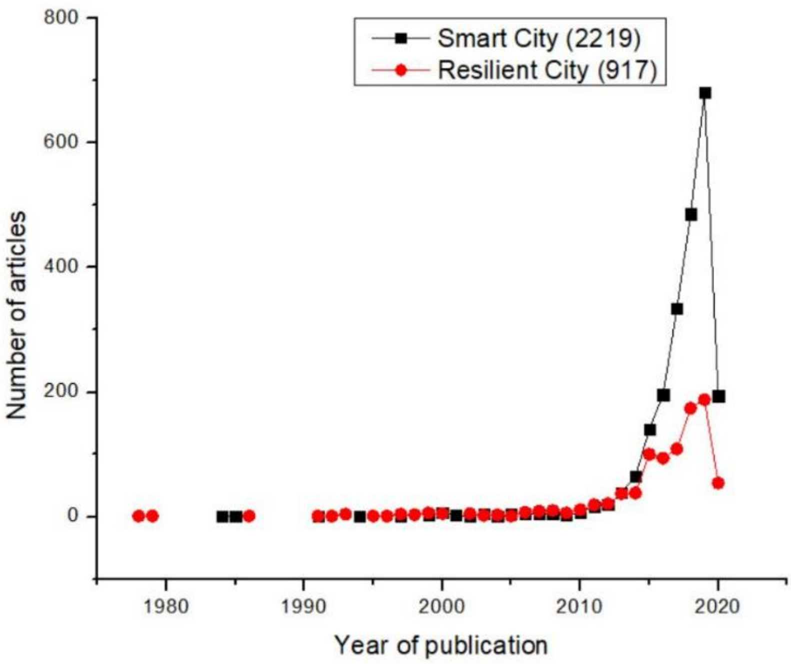


FIGURE 2 Time distributions of articles in SC and RC

3.2 Differences in research category

The research category helps to illustrate the disciplines engaged in SC and RC studies. According to the WoS search analysis, the SC articles covered 128 categories and RC publications yield 122 categories, together with a total of 150 categories. Among them, 100 categories of SC and RC studies are the same, accounting for 66.7% of the total (150). The top 10 WoS categories for SC and RC are summarized in Table 1.

Six categories in SC studies are related to engineering, telecommunication and computer science. Publications in these categories account for 79.5% of all publications. All the top 10 categories for RC studies are related to environment, urban science and geography. Although some categories, such as “environmental studies”, “green sustainable science technology”, “urban studies”, and “environmental sciences” are common categories for SC and RC studies, the number of publications varies greatly. This implies that SC covers more multidisciplinary sciences than RC. They have both made different contributions to urban research, but SC pays more attention to technology and computer science.

TABLE 1 Research category for SC and RC studies (summarized with WoS search analysis)

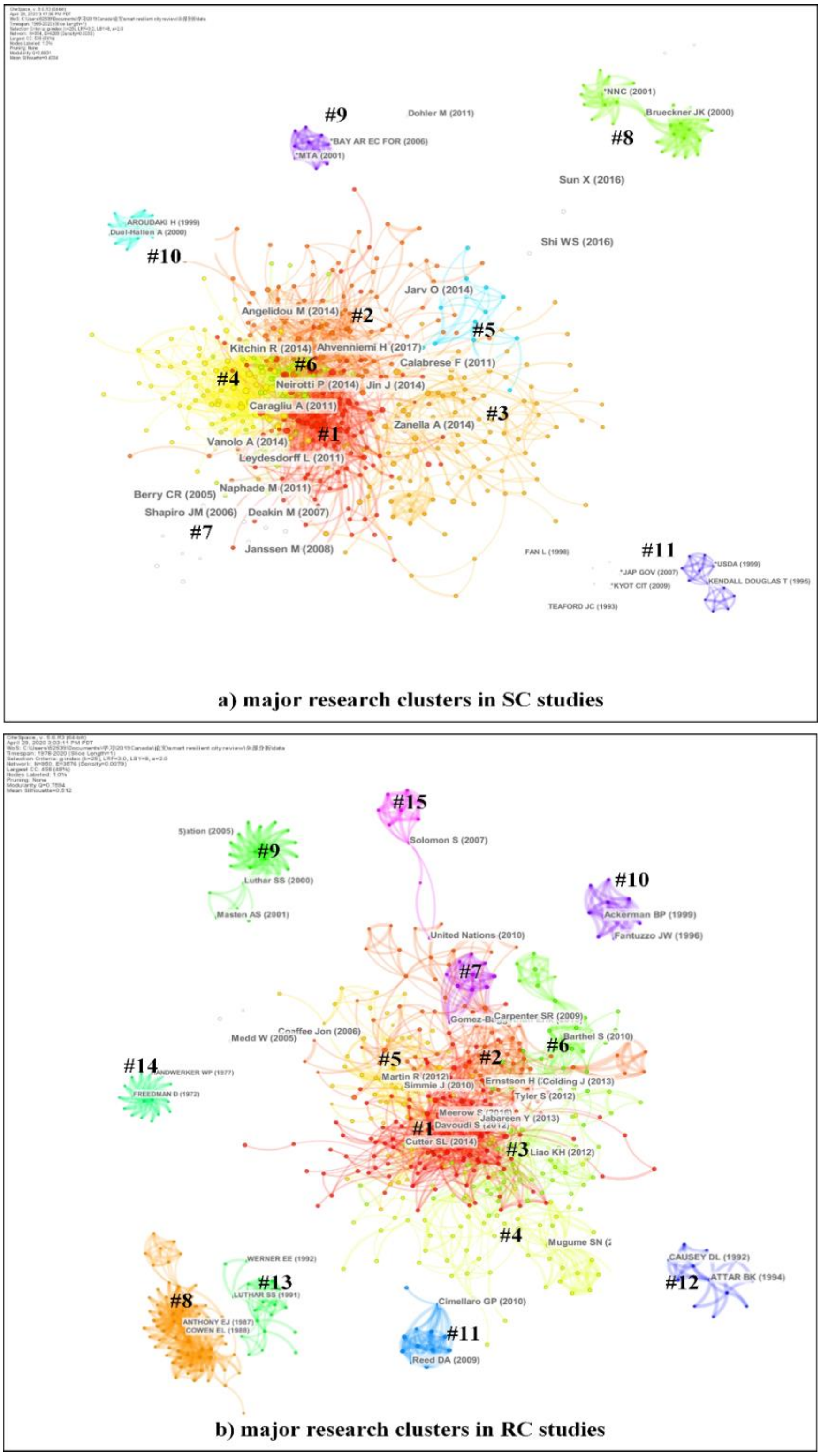
No.	Research category	Publications in SC	Research category	Publications in RC
1	Engineering electrical electronic	502	Environmental studies	221
2	Telecommunications	447	Environmental sciences	198
3	Computer science information systems	435	Urban studies	128
4	Green sustainable science technology	179	Water resources	113
5	Environmental studies	178	Green sustainable science technology	92
6	Urban studies	162	Meteorology atmospheric sciences	61
7	Computer science theory methods	153	Regional urban planning	61
8	Environmental sciences	150	Geography	56
9	Instruments instrumentation	116	Public environmental occupational health	56
10	Computer science interdisciplinary applications	112	Geosciences multidisciplinary	54

3.3 Differences in research clusters

In order to further compare the research hotspots of SC and RC, the previous articles in

SC (2219) and RC (917) are imported into *CiteSpace* for visualization and analysis of the co-citation network. The document co-citation network is divided into a number of clusters and labels are automatically assigned to different clusters using the most important terms extracted from keywords, titles, or abstracts (Chen et al., 2010). Besides, two network measurements are used to evaluate the co-citation network, one is modularity and the other one is silhouette. Modularity measures the strength of a network in SC and RC research clusters. The value of modularity close to 1 means strong network structure (Chen, 2014). The silhouette of each cluster is used to indicate its homogeneity, and higher silhouette value means more consistent cluster members when the clusters are of a similar size (Lovmar et al., 2005). Therefore, the articles in the same cluster can be considered as well matched in their own cluster and poorly matched to other clusters. In this way, the research cluster can be revealed, the integrating network visualization and the automatic cluster labeling can help to identify the specific main research areas, contents and themes of SC and RC studies.

As shown in Figure 3(a), a 954-node and 4209-link hybrid network of co-cited references in SC research is constructed with eleven major clusters. Similarly, in Figure 3(b), a 950-node and 3576-link hybrid network of co-cited references in RC research is also constructed with fifteen major clusters. The modularity values for SC and RC are 0.6631 and 0.7594 respectively, which means the quality of the overall higher-level division showing a better structured network (Chen et al., 2010). And the silhouette value for the SC clusters ranges from 0.668 (#1) to 0.984 (#11), and from 0.629 (#1) to 0.994 (#15) for RC clusters. Both the modularity and the silhouette value (larger than 0.5) suggest that the network is reliable. The clusters are illustrated with different colors and each node in the cluster presents one article. The research hotspots for SC and RC studies can be then analyzed from the labels and contents of the articles in the identified cluster.



a) major research clusters in SC studies

b) major research clusters in RC studies

FIGURE 3 Visualization of SC and RC major research clusters (generated by *CiteSpace*)

In order to compare major research hotspots, an in-depth content analysis of the articles in the top five clusters for SC and RC studies is conducted. Their size, silhouette value, and label are summarized in Table 2. Among them, the label is generated automatically by the *CiteSpace*

Log-Likelihood Ratio (LLR) test method , which is considered to be the most popular and best cluster label selection method (Chen et al., 2010). The hotspots of the SC and RC studies can be summarized from the manual review of the articles in the top five research clusters.

TABLE 2 Top 5 major clusters of co-cited references in SC and RC research

#	Size	Silhouette value	Label for the cluster (LLR)
SC studies			
1	134	0.668	Building smart city
2	123	0.755	Technology guide
3	111	0.750	Smart sustainable cities
4	92	0.783	Citizen-centric challenge
5	49	0.806	Fog computing
RC studies			
1	137	0.629	Climate resilience
2	81	0.711	Defining urban resilience
3	60	0.776	Urban infrastructure system
4	56	0.780	Water management
5	32	0.896	Resilient urban design

3.3.1 SC research hotspots

For SC studies, the largest cluster labeled as "building smart city" focuses mainly on the concept, planning and practice of SC. The most cited article in this cluster reviewed the definition, performance and initiatives of SC with discussions on three main contexts of SC, namely technology, people, and community (Albino et al., 2015). More strategic planning, development and practice of SC (Angelidou, 2015; Lee et al., 2014) are reviewed and discussed in this cluster with its performance factors (Caragliu et al., 2011), evolution patterns (Neirotti et al., 2014), and rudiments (Batty et al., 2012). Nearly all papers in this cluster mention that SC is a fuzzy concept used in inconsistent ways which are not available with a shared definition, but agree that information and communication technology (ICT) is the core component for SC, that should be considered in the construction of SC.

Following immediately, the second cluster, labeled as "technology guide" reveals the core component of SC, which is the adoption of technology. Back in 2011, SC was officially registered as a trademark of IBM, which laid the foundation for the implementation of urban technologies (Söderström et al., 2014). The most cited article in cluster #2 summarized SC as a convergence of technology and the city, which has three drivers (community, technology, policy) and five desired outcomes (productivity, sustainability, accessibility, wellbeing, livability, and governance) (Yigitcanlar et al., 2018). Other highly cited articles introduced major technologies adopted in SC, especially the urban bid data analytics from stakeholders and physical objects in the city (Lim et al., 2018), and the Internet of Things (IoT) is one of the key components of ICT infrastructure for SC (Bibri, 2018; Zanella et al., 2014). Similarly, the fifth cluster also discusses the innovation and future directions of technology used in SC. In order to deal with massive volumes of data, various research directions on SC techniques are explored, such as cloud computing (Hossain et al., 2018), virtual reality (Lv et al., 2016), and sensing devices (Tawalbeh et al., 2016; Teng et al., 2019). It is also expected to connect large SC with small smart home (SH) to the Fifth Generation (5G) wireless system and ensure energy efficiency and resource utilization (Coll-Perales et al., 2019; Orsino et al., 2016). Recently, compared to cloud computing, researchers like Perera et al. (2017), He et al. (2018) and Cheng et al. (2018) have all viewed fog computing as an more affordable and sustainable computing paradigm to enable IoT services in SC. Therefore, in these two clusters, the guidance and adoption of technology has been confirmed in SC initiatives, and the expansion of big data and the evolution of IoT are explored and hoped to further support the data analytics service, resource allocation and SC performance in the future.

The other two clusters, labeled as “smart sustainable cities” and “citizen-centric challenge”, focus specifically on the problems, challenges, and governance for further SC development. Cluster 3 focuses on the development between SC and the environment. It is argued by the researchers that whether the SC can contribute to the goal of sustainable development (Bibri & Krogstie, 2017b). Current SC frameworks are often lacking in environmental indicators (Ahvenniemi et al., 2017), and the form of ICTs can pose risks to environmental sustainability (Bibri & Krogstie, 2017a). The construction of SC needs to be reoriented in a more environmentally sustainable direction. Accordingly, a framework for strategic smart sustainable urban development was established (Bibri, 2018b) and the environmental benefits derived from the implementation of smart sustainable urban initiatives with IoT and big data applications were discussed (Bibri, 2018a).

Besides technology, practices and operations of citizenship is another problem and challenge for SC governance (Gabrys, 2014). The most actively cited article in cluster #4 mentioned that citizens are the primary beneficiary of SC initiatives and identified six citizen-related challenges, namely the engagement of citizens, the improvement of citizens' data literacy, the pairing of quantitative and qualitative data, the need for open standards, the development of personal services, and the development of persuasive interfaces (Degbelo et al., 2016). On this basis, Joss et al. (2017) proposed that SC should be more citizen-centric and less technology-oriented. Furthermore, as data, city and governance are closely linked, urban algorithmic governance and governmentality should also be anticipated in the development of SC (Leszczynski, 2016). Some also argued the corporate and entrepreneurial governance in SC practice (Hollands, 2015). Most of the papers in this cluster come from social considerations, addressing the importance and collaboration of the various stakeholders involved (Kitchin, 2015).

3.3.2 RC research hotspots

For RC studies, the largest cluster, labeled as "climate change", focuses mainly on the drive and origin of RC. The most actively cited paper (Leichenko, 2011), titled as "*Climate change and urban resilience*", pointed out that cities must become resilient in order to be prepared for climate change. It is agreed that the earth's climate has changed throughout the history, urban systems and populations are exposed under the unavoidable changes. Sea level changes, storms, enduring heat and drought, and other kind of extreme weather events pose great challenges to urban area, particularly coastal cities (Wardekker et al., 2010). To address this challenge, Tyler and Moench (2012) developed a framework to illustrate how to contribute to urban climate resilience planning and practice with the characteristics of urban system, people and organizations. Giving the increasing risk and unpredictable climate change, Doherty et al. (2016) emphasized the motivation and capacity of urban areas for adaptation and resilience to facilitate long-term adaptation strategies (Dhar & Khirfan, 2017). It is concluded that in this cluster, huge challenges for urban living are induced by climate change and therefore urban resilience is expected to build adaptability and respond to future climate change scenarios.

The second cluster in RC is concerned with its concept definition. Based on the concept of resilience first given by Holling (1973), various RC definitions are proposed. The most highly cited article in this cluster defined RC as a strong, flexible and sustainable network of physical systems and human communities (Godschalk, 2003). Pickett et al. (2004) put the RC concept into an ecological-social framework and discussed two opposing paradigms on RC, equilibrium and un-equilibrium. Based on the previous literature review on the inconsistent definition of urban resilience, Meerow et al. (2016) defined six conceptual tensions that are fundamental to urban resilience: urban, system equilibrium, positive vs. neutral, mechanism for system change, adaptation and adaptability, and timescale of action.

The following three clusters are all related to specific considerations and resilience planning. Cluster #3 focuses mainly on the infrastructure resilience. As cities are infrastructure-mediated geographical nodes with a high-density population, they are particularly vulnerable to infrastructure failures (Huck & Monstadt, 2019). The most highly cited article proposed a multi-stage framework for infrastructure resilience analysis and tested it with both single and multiple hazards on power transmission grid (Ouyang et al., 2012). In addition, the related studies also focus on developing infrastructure resilience from a single system (e.g. power, water) (Cimellaro et al., 2016) to critical infrastructure networks (Fotouhi et al., 2017; Serre & Heinzlef, 2018), and exploring their coupling relationship under disasters. Cluster #4, labeled as "water management", mainly focuses on the flood resilience. A number of studies have agreed that resistance floods by traditional methods such as dams cannot address the extreme events due to increased climate change (Bodoque et al., 2016; Klijn et al., 2004). The most highly cited paper developed a theory on "urban resilience to floods" as a reliable approach to long-term flood safety (Liao, 2012). Evaluation frameworks are designed to measure the flood resilience level of the city with indicators form social, economic, physical and environmental dimensions (Hammond et al., 2018; Serre & Heinzlef, 2018) or from flood mitigation drivers, such as drainage system capability, hazard characteristics, income variable and material recovery ability (Bertilsson et al., 2019). Cluster #5 mainly focuses on RC planning and governance. The most highly cited paper in this cluster developed an RC planning framework with dimensions of vulnerability analysis, prevention, uncertainty oriented planning and urban governance (Jabareen, 2013). It is also noted in this paper that a wide range of stakeholders need to be considered in the RC planning. Detailed introductions to RC governance are provided by Beilin and Wilkinson (2015), arguing for the connections between the ecosystem and human society in urban resilience governance.

3.3.3 *Discussion of Research differences between SC and RC studies*

Co-citation analysis helps to identify the research hotspots in SC and RC studies respectively. The comparisons between their research hotspots are followed by a manually in-depth review of the abstract of the articles (for majority of the papers) and the whole paper if the abstract is more relevant and methods or findings are interesting or novel. After the comparison, the major differences between SC and RC studies are summarized in four points, including their research objectives, driving force, current research focus and criticism, as shown in Table 3.

TABLE 3 Major differences in SC and RC studies

Differences	SC studies	RC studies
Objective	How to make city smart?	Why the city need to be resilient and what is RC？
Driving force	Promote creativity and provide better and convenient life (active process)	Disaster prevention and mitigation (passive process)
Current research focus	ICT and modern technologies adoption and evolution (from zero to higher degree)	Concept definition and resilience assessment (from existing level to future expectation level)
Criticism	Side effect of technology; Less care for environmental and social issues	Not seen

(1) Objective

After screening the main contents of the identified clusters, SC and RC studies are found with different objectives in solving urban problems. In SC, the largest cluster aims at the planning and practice of SC. Other clusters are concerned with the technology adoption and evolution, as well as the challenges of SC in environmental and social fields. The key point of these studies answers the question of how to make city smart and how to build SC better. On the other hand, the largest cluster in RC focuses on the climate change issues, and the following RC clusters provide a detailed definition of resilience in city and urban infrastructures. In general, these RC studies try to answer the question of what is RC and why the city needs to be resilient. Thus, the objective of existing RC studies remains at the stage of concept definition and recognition, while SC studies are already at the stage of application.

(2) The driving force

Researchers stated that the application of the IoT paradigm to the urban context is the major driving force for SC studies, and creativity is one of the key factors (Arafah & Winarso, 2017; Zanella et al., 2014). Many researches are therefore seeking advanced technological solutions to the pressing issues related to urban development and management (Caragliu et al., 2011; Viitanen & Kingston, 2014). The motivation is to make better use of public resources, enhance the quality of services provided to residents and reduce the operating costs of public administrations (Zanella et al., 2014). On the other hand, the RC tends to focus on natural hazards mitigation, which is one of the most widely mentioned driving forces when defining RC (Leichenko, 2011; Meerow et al., 2016). Zhang and Li (2018) summarized RC as a passive process of finding ways to maintain and recover from external influencing factors. In this way, SC can be described as an active process for finding ways to better improve the service with the adoption of ICTs.

(3) Current research focus

SC is an active process to promote creativity and provide a better and more convenient life, focusing mainly on the use and evolution of ICT and modern technologies, such as cluster #2 and #5 for SC shown in Table 2. The smartness of the city is considered to be created from zero to some degree. Thus, numerous practical methods and models such as software platforms, data mining, and sensor monitoring are built to pursue the applications of SC and increase the level of urban smartness (Pan et al., 2013; Santana et al., 2017; Shin et al., 2015). However, the main focus of RC studies is on its concept definition and assessment, which is not as mature as SC development. A large number of RC researches have already answered the question why the city needs to be resilient. It is agreed that resilience is one of the inherent attributes of the city (Khailani & Perera, 2013; Rapaport et al., 2018). The real challenge is how to measure the urban resilience and how to improve the resilience from the existing level to the expected levels. Thus, many assessment frameworks have been developed to evaluate the resilience from consideration of its own composition (e.g. infrastructure resilience in cluster #3) and external threats (e.g. flood resilience in cluster #4).

(4) Criticism

With increasing concerns about natural hazards (e.g. floods, earthquakes, hurricanes) and social problems (e.g. terrorism, COVID-19, poverty), RC is considered to be capable of responding to both types of threats (Bertilsson et al., 2018; Godschalk, 2003; Sanders et al., 2008). What's more, considering more than 66% urban population in 2050 (United Nations, 2014), the exiting studies all consider RC as a future-oriented city to be prepared for various urban crisis. Unlike the promotion for RC, the practice of SC is considered as a double-edged sword. Almost half of the articles (especially in cluster #3 and #4) mentioned the side effects of SC, such as the problem induced by fast developed technology, and the neglect of environmental and social development. Solutions are proposed to address issues such as network fragile, web security, data loss, public privacy, and equality (Durand et al., 2011; Kotevska et al., 2017; Y. Li et al., 2016). As mentioned in cluster #3 for RC in Table 2, sustainability is one of the greatest challenges for SC (Aina, 2017; Li et al., 2019; Yigitcanlar et al., 2019). Thus, the sustainable development of SC becomes very popular as a future research trend.

4. CONNECTIONS BETWEEN SC AND RC

Among the above 2219 articles in SC and 917 articles in RC studies, after scanning the title and abstract, only 25 articles are found to be both related to SC and RC studies, including the repeated articles. Therefore, a total of 25 articles are used to explore the connections between SC and RC by comparing the entire content of the paper.

4.1 Overview of the studies related to both SC and RC

Among the 25 articles, three are literature reviews about the concept of SC and RC. Since many city-related terms are used by policy makers, planners and developers, De Jong et al. (2015) compared the concepts of eleven kinds of cities, including SC and RC, and the results show no obvious connection between the two concepts. Papa et al. (2015) identified some common characteristics of SC and RC by comparing their concepts, namely adaptability, awareness, collaboration, creativity, diversity, efficiency, flexibility, innovation, learning, networking, and participation. Later, Hatuka et al. (2018) reviewed these concepts in the context of the political environment and made some comparisons between SC and RC from the view of government and residents, without mentioning their connections. Besides, Dong et al.(2020) evaluated the resilience of SC in China and analyzed their temporal and spatial differences, but did not mention their connections.

The rest of the 21 articles have more or less revealed the connections between SC and

RC. The research topic, category and main conclusions or contributions of these articles are summarized in Table 4 by manually reading their full contents. It is found that the earliest article was written by Takewaki et al. (2011) introducing a kind of smart passive damper used for safer and more reliable buildings under external attacks. Then, research related to both SC and RC are discussed with various topics and gradually increased since 2014. Such as physical-related construction & building technology, environment-related environmental science and energy & fuels, and social-related public, environmental & occupational health. Research topics are matched with their categories, covering from specific smart technologies (e.g. IoT, big data) to a wide range of urban science (e.g. green growth, urban design). Based on the conclusions and contributions of the articles studied, two main directions were summarized in the discussion of the connections between SC and RC. One explores their connection from the point of SC, such as Takewaki et al. (2011), and Eder-Neuhauser et al. (2016). Another explores their connection from the point of RC, such as Abreu et al. (2017) and Kotevska et al.(2017). Thus, the articles can be divided into two groups to discuss their connections: the effect of SC on RC and the effect of RC on SC.

TABLE 4 Overview of the researches related to both SC and RC

No.	Articles	Research topics	Research category	Main conclusions or contributions
1	Takewaki et al. (2011)	Smart passive damper	Construction & Building Technology	Smart passive damper helps to build earthquake resilience.
2	Viitanen & Kingston (2014)	Green growth	Environmental Studies; Geography	SC may exacerbate existing inequalities and risks rather than resolve them, making the city less resilient in face of future social and climate disasters.
3	Boulos et al.(2015)	Social equality	Public, Environmental & Occupational Health	Technology is not a panacea, and other factors are equally important when it comes to creating happier and healthier cities and regions.
4	Fujinawa et al.(2015)	Resilient smart city	Geosciences	SC can help to provide information on disaster prevention and to improve resilient to nature
5	Gargiulo & Zucaro(2015)	Energy saving	Urban Studies	Explored the strategies to reduce energy consumption and improve energy resilience through smart planning.
6	Eder-Neuhauser et al. (2016)	Smart grid	Computer Science, Information Systems	Adding ICT into smart grid can lower its resilience and security.
7	Kavehvash (2016)	Intelligent transportation system	Engineering	ICT's role in creating resilient city is to build cost-effective and resource-efficient infrastructure systems for smart cities.
8	Hiller & Blanke(2017)	Privacy	Government & Law	Discussed how privacy in a smart city with resilience theory can adapt and survive.
9	Kaika(2017)	New urban agenda	Environmental Studies; Urban Studies	Smart cities and ICTs are part of the problem of urban resilience.
10	Abreu et al. (2017)	IoT application	Telecommunications	Resilience of infrastructure in the IoT is necessary for SC
11	Kotevska et al.(2017)	Data loss in SC	Computer Science,	SC services require a level of resilience to data stream disruption

			Information Systems	based on its application domain and data rate frequency.
12	Beck (2017)	Infrastructure and human security	Engineering, Civil; Transportation	SC may be vulnerable to cyber security attacks and attacks on physical infrastructure and human life.
13	Kim & Kim(2017)	Debris clean up technique	Remote Sensing	Used smart method for resilient debris clean up.
14	Garnett & Adams(2018)	Light detection and ranging (LiDAR) data for urban resilience	Geography, Physical; Remote Sensing	Proposed applications of LiDAR-A technology to support the goals and objectives of the RC.
15	Moraci, Errigo, et al. (2018)	Resilient urban design	Environmental Sciences; Environmental Studies	RC is a concept within the meaning of SC and is considered to be part of the smart planning paradigm.
16	Moraci, Fazia, et al.(2018)	Energy supply	Multidisciplinary	SC can help to achieve efficient management of urban resources in order to pursue energy resilience in the city.
17	Shah et al. (2019)	Disaster mitigation	Computer Science, Information Systems	Recent advances in technology have provided an open opportunity for the development of disaster resilient smart city environments.
18	da Silva et al. (2019)	Urban resilience and human well-being in SC	Social science; management	Explored the relationships between urban resilience and human well-being in SC.
19	de Falco et al.(2019)	Urban intelligence and resilience	Environmental Studies; Urban Studies	Recognized the potential of SC to enhance the resilience of metropolitan areas.
20	Zach et al.(2019)	Energy supply	Energy & Fuels	Smart energy planning in urban development zones can offer new options for RC.
21	Zhu et al.(2019)	Urban smartness and resilience	Green & Sustainable Science & Technology	Illustrated the impact of urban smartness on RC from infrastructural, economic, social, institutional and environmental aspects.

4.2 Discussion on connections between SC and RC

As shown in Table 5, RC effects on SC (or the SC effects on RC) can be grouped into two sides: one is the positive effect (+) and the other is the negative (-). Besides, according to their research topics and categories, the effects are also considered from three dimensions, which are physical, social and environmental dimensions.

TABLE 5 Major connections between SC and RC in selected articles

Effect direction	Effect dimension	Effect	Supported articles
RC on SC	Physical	+	Abreu et al.(2017), Kotevska et al.(2017)
	Social	+	Moraci, Errigo, et al. (2018), Hiller & Blanke(2017)
	Environmental	+	Moraci et al. (2018a)
SC on RC	Physical	+	Kavehvash (2016) , Kotevska et al. (2017), de Falco et al. (2019), Zach et al. (2019), Gargiulo & Zucaro(2015), Moraci, Fazia, et al.(2018), Zhu et al. (2019), Fujinawa et al.(2015), Shah et al. (2019), Takewaki et al.(2011), Boulos et al. (2015), Kim & Kim (2017)
		-	Kotevska et al.(2017), Eder-Neuhauser et al.(2016), Beck (2017)
	Social	-	Kaika (2017), Viitanen & Kingston (2014), Beck (2017)
	Environmental	-	Kaika (2017), Viitanen & Kingston (2014)

"+" means positive effect; "-" means negative effect.

It is found that the effects of RC on SC are all positive. These studies prove that resilience can help to achieve SC and is essential to SC planning in all the three dimensions (Moraci, Errigo, et al., 2018). For example, in physical aspect, the resilience of infrastructures in IoT is necessary for SC (Abreu et al., 2017) and helps to overcome the negative effects of SC, such as data stream disruption (Kotevska et al., 2017). In social and environmental aspect, RC can act as a foundation for SC planning (Moraci, Errigo, et al., 2018) and help the adaptation and survival of privacy in SC (Hiller & Blanke, 2017).

The effect of SC on RC has two sides. It has been proved by many researchers that the introduction of smart technologies and thinking can have positive functions for RC development in physical aspect (de Falco et al., 2019). For example, modern ICTs, such as IoT and big data analytics technology provide an open opportunity to develop RC (Shah et al., 2019). They can help improve the intelligence of transportation system (Kavehvash, 2016), optimize resource allocation in energy supply (Gargiulo & Zucaro, 2015; Moraci, et al., 2018;

Zach et al., 2019), provide disaster prevention information (Takewaki et al., 2011) and improve resilient against nature (Fujinawa et al., 2015). The positive effect of SC on RC from social and environmental aspects is not clearly stated, but is statistically approved by Zhu et al. (2019) with samples cities in China. They find that SC mainly contributes to urban infrastructure, economic and institutional resilience, but has little impact on social and environmental resilience.

On the other hand, the effects of SC on RC also have some negative effects on physical, social and environmental aspects. In physical aspect, as SC services are highly data-dependent, they are more susceptible to disruptions in data streams (Kotevska et al., 2017), which makes physical infrastructure less resilient to security threats (Beck, 2017). Besides, adding ICT also create additional entry points in vulnerable hardware and software, increasing the attack surface, harming the resilience (Eder-Neuhauser et al., 2016). In social and environmental aspect, SC is pushing cities to become less resilient, facing future social and climate risks with less consideration for the environment and public equality and justices (Kaika, 2017; Viitanen & Kingston, 2014). These negative effects are consistent with the weaknesses and challenges faced by SC mentioned in Section 3.3.1.

Therefore, the qualitative analysis of the connections between SC and RC demonstrated the existence of their connections. Although the articles are limited, they have received more and more attention in recent years. Current findings of the connections between SC and RC implies that they are both important and necessary for urban development and they can possibly be worked together through wise planning and governance.

5. SUGGESTIONS

The literature review and the qualitative discussion explored the major differences and connections between SC and RC. The result implies that it has gradually attracted the attention of researchers to consider SC and RC together, and the effect between them poses new directions for dealing with urban problems or disasters in the future. Major suggestions for future researches are summarized as follows:

(1) Considering the greenhouse gases mitigation and climate change adaptation, improving urban resilience is essential. Current RC research mainly focuses on the concept definition and recognition stage, which needs further exploration and application. It is suggested to continue deepening the theoretical and practical research of RC in order to deal with future unknown disasters from both nature and human sides, such as issues relate to the real-time model building, resilient plan and governance, and multi-disaster mitigation strategy. It is also encouraged to integrate smart thinking and technology into the improvement of urban resilience.

(2) More research can be conducted on the environmental and social aspects of SC construction. As cities are complex organisms consisting of the physical environment, human beings and their interactions, technology alone cannot solve the social problems in cities. Current research has noticed the weakness and challenges for SC development and highlighted the importance of people and community in building SC. It is necessary to continue and focus more on the environment and social parts in life-cycle planning and practice of SC. Further studies are suggested on the issues related to SC ecosystem construction, SC perception, satisfaction and equality.

(3) It is highly recommended that SC and RC should be cooperated together in dealing with urban problems, natural and social disasters. The current theoretical and empirical work shows that SC and RC can work together and complement each other with proper design and governance. Thus, it lights the vision to consider them together and build a resilient smart city (RSC) (Fujinawa et al., 2015). In the context of the widespread application of information technologies, there are more and more junctions between SC and RC. RSC can be seen as a combination of SC and RC, which allows them to jointly promote the safety, happiness and sustainability of the city. The hardware and software that was built in the construction of SC can be used to support and improve urban resilience, such as the disaster warning system. Massive information collected from various industries in the construction of SC can be shared as part of the data required for the construction of RC. At the same time, the improvement of the city's existing disaster prevention and mitigation capabilities through RC construction can also be reflected in various basic databases and related applications of SC. In this way, RSC can integrate the construction and management of SC and RC into a futuristic city that integrates “smart” in daily operations with “resilience” in disaster scenarios.

Relevant studies are therefore suggested to continue providing more opportunities for RSC to develop frameworks pursuing resilience with smart technologies such as IoTs, big data, powerful computing, artificial intelligence and digital twins. It is also hoped that sensible paths and strategies for design, planning and governance of RSC will be proposed, while having an active effect on both SC and RC development. Continually integrating multidisciplinary sciences, such as engineering, computer science, and social science, can be a support for further development of RSC.

6. CONCLUSION

The growing concerns about urban problems and urban stresses in nature reflect the global interest in SC and RC. However, the initiatives of the two terms are mixed, confusing and even debated. Thus, this paper explored the differences and connections between the two initiatives with a comprehensive literature review on SC and RC. A total of 2219 SC articles from 1984 to April 2020, and 917 RC articles from 1978 to April 2020 from the WoS database were collected as the sample for scientometric analysis.

Differences between SC and RC are discovered from their research trend, category and clusters. The results show that SC is developing much faster than RC from the article amount and trend. Major categories for SC lie on engineering, telecommunication and computer science, while the studies in RC mainly focus on environment and urban field. Research hotspots are identified through their research clusters and four major differences are found from comparison: research objectives, driving force, current research focus and criticism. 25 articles related to SC and RC are thoroughly reviewed in order to explore their connections. RC effects on SC from physical, social and environmental aspects are found positive, while SC effects on RC are found with both positive and negative sides. The identified differences and connections implies that SC and RC are both necessary for the urban development and should be paid equal attention before decision-making.

The literature review of current research provides a summary of the studies on SC and RC, and helps to better understand their origin, driving force, and research hotspots. These findings can be used as guidance for researchers and city decision-makers in SC and RC constructions and governance. The progress and evolution of SC and RC studies can also inform their further research and practical directions, and the proposed RSC construction is expected to improve future urban life, disaster response and mitigation.

Funding Information

This project is funded by the National Social Science Foundation of China (No. 19BGL281), the National Key Research and Development Program (No. 2018YFD1100202), the Jiangsu Social Science Foundation Project (No. 18GLB002), the Postgraduate Research & Practice Innovation Program of Jiangsu Province (No. KYCX18_0203), and the support provided by China Scholarship Council (CSC).

Acknowledgement

The authors would like to thank Dr. Gyan Chhipi-Shrestha and Dr. Kh Md Nahiduzzaman for their research assistance and advices.

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