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Knowledge Domain and Emerging Trends of Intelligent Green Building and Smart City – A Visual Analysis Using CiteSpace

Hongyang Li [1, 2, *], Mingjie Dai [3]

[1] *Lecturer, School of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510641, China. Email: li.terryhy@yahoo.com ([*]Corresponding author)*
[2] *State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou 510641, China.*
[3] *Depatment of Real Estate and Construction, School of Architecture, the University of Hong Kong, Hong Kong, China.*

Abstract: As the concept of sustainability becomes more and more popular, a large amount of literature have been recorded recently on intelligent green building and smart city (IGB&SC). It is therefore needed to systematically analyse the existing knowledge structure as well as the future new development of this domain through the identification of the thematic trends, landmark articles, typical keywords together with co-operative researchers.

In this paper, Citespace software package is applied to analyse the citation networks and other relevant data of the past eleven years (from 2006 to 2016) collected from Web of Science (WOS). Through this, a series of professional document analysis are conducted, including the production of core authors, the influence made by the most cited authors, keywords extraction and timezone analysis, hot topics of research, highly cited papers and trends with regard to co-citation analysis, etc.

As a result, the development track of the IGB&SC domains is revealed and visualized and the following results reached: (i) in the research area of IGB&SC, the most productive researcher is Winters JV and Caragliu A is most influential on the other hand; (ii) different focuses of IGB&SC research have been emerged continually from 2006 to 2016 e.g. smart growth, sustainability, smart city, big data, etc.; (iii) Hollands's work is identified with the most citations and the emerging trends, as revealed from the bursts analysis in document co-citations, can be concluded as smart growth, the assessment of intelligent green building and smart city.

Key words: Intelligent green building, Smart city, Citespace, Visualization, Web of Science

INTRODUCTION

Sustainable development was defined by the World Commission on Environment and Development (WCED) as an integrated approach for addressing concerns regarding a number of environmental and socio-economic issues[1]. Intelligent green building and smart city are both essential topics in this domain.

With regard to intellgent green building, in 2010, a program entitled "four emerging intellectual industries" was launched in Taiwan, China with intelligent green buildings included[2]. By promoting the concept of intelligent green building, this program strived to stimulate the technological development of the architecture, engineering and construction (AEC) industry and established a sustainable living environment with reduced carbon emission and energy consumption. In mainland

China, intelligent green building is also emphasised by both practitioners and academia. The main research trends have shifted from analysing the application of smart technology in a single building to the implementation at the regional level (e.g. subtropical area), resulting in another concept of smart city. Through this, safer and greener communities are expected to be built[3].

Many researchers have devoted to pursuing the true spirit of smart city. Nearly ten years ago, Richard Hollands pointed out that though declaring smart many cities have not even figured out its definition [4]. To deal with this, many researchers have proposed their opinions. Among them, the most popular one was raised by IBM, stating that smart cities should use new technologies to transfer the data systems which measure and influence each aspects of cities from entities to a net where information can flow freely, in order to optimize the use of finite resources[5]. Meanwhile, other research has been done to locate the factors affecting smart city, for example, Caragliu *et al* found out such indices as the creative class, the level of education, the use of ICTs (Information and Communication Techologies) for public administration, and so on[6].

Recently, the trend of intelligent green building and smart city concept is increasingly focusing on the internet technology (IT). Kirby assumed that the life of the citizen of the intelligent green building and smart city is widely support by IT, including payment, transportation, remote communication[7]. Some researchers however emphasised on energy management of intelligent community and the components of smart city[8], which is now updated to the early warning of energy and environmental dangers by using the Big Data technique. Nowadays, big data has become a useful tool to analyze and maximize the utilize of space and resources so that the smart cities could keep eco-friendly. Many researchers, on the other hand, have noticed that, due to the rapidly growing global population, it is critically important to exploit the spatial development potentials in terms of either taller sustainable buildings or more innovative waste management. Yet the top concern when creating a smart city is to keep it eco-friendly and to work towards a cleaner and greener future for us[9].

Being different from the previous research on IGB&SC, this paper applies Citespace to conduct a scientometric review of this area from 2006 to 2016. By using Citesapce, functions of information visualization and mapping knowledge domains are adopted to explore the current situation of IGB&SC research, find out the hot topics in the literature, and illustrate the emerging trends for further analysis. As a result, we first design to search out the most productive and influential contributors through co-author analysis and cited-author analysis. Based on co-word analysis at the keyword level, we then attempt to identify the primary research keywords and their variations through years. A thorough identification of the hot topics and the emerging trends in the IGB&SC research finally concludes the paper.

RESEARCH PROCESS

1. Author Analysis

1.1. Co-author Analysis

Based on the co-authorship analysis of the author information collected from the WOS database, a co-author network with scholars' production and their cooperation network is obtianed in Fig. 1. To some degree, an author's level of productivity can be representative of the devoted efforts of that researcher, hence, co-authorship network is able to search out a small group of productive authors who have contributed large numbers of publications on IGB&SC research. There are 144 nodes and 138 links in the network, the size of the nodes labeled by authors' names stands for the author's output quantities, the links between each author represent their direct partnerships.

In Figure 1, it is clear that Winters JV is the most productive author in the IGB&SC research, followed by Bisegna F, Gabarrell X, Hollander JB and Jucevicius R. Furthermore, Figure 1 is almost constituded by incompact nodes without enough connection links, suggestting that the communication and cooperation between each author are not very close in the area of IGB&SC . Scholars prefered doing their reseach individually or within their own teams. In spite of this, there are still some small-scale cooperations of three to six members who are conducting some relvent researches, for instance, Vitalisova K, Borsekova K and Vanova A formed a team, in which Vitalisova K is the most productive member. It is a common phenomenon that several researchers choose to work with a highly

productive author, like Gabarrell X, who is a central author of his team, in which scholars Villablba G and Rieradevall J are inclusive.

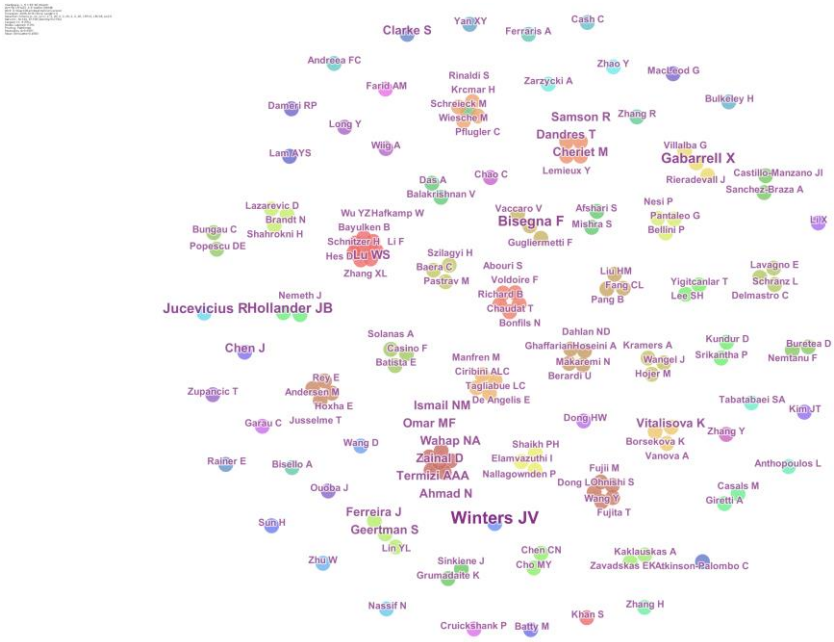

Fig. 1. Network of co-author analysis, with 144 nodes and 138 links

1.2. Cited-author Analysis

The most highly productive authors are not directly equal to the authors who contribute most to the research of intelligent green building and smart city. For the purpose of finding out the comparision between authors with high production and those with high levels of co-citation, we use cited-author analysis, a powerful tool to excavate the contribution of various researchers. The principle of cited-author analysis is to figure out the relationships between the authors' publications which have been cited in the identical paper, and then measure their contributions by the co-citation frequency. The principle can be interpreted as the more an author's work is cited, the more this author has contributed to the IGB&SC research.

As shown in Figure 2, the cited-author network contains 2,040 nodes and 5,809 links. The size of each node reflects the quantity of citations of the author it represents, the links between authors represent indirect cooperative relationships established based on citation frequency, and the link's color stands for the first time when authors are co-cited.

The most highly cited authors and their citation frequencies are revealed in Fig. 2. Caragliu A (74), Hollands R (73), European Commission (61), Florida R (57) and Komninos N (54) occupy the top 5 most cited authors. Compared with the most productive authors explored in the co-author analysis, the result reveals that the correlation between production and contribution is not very relevent. Not all highly productive authors have a similarly high influence on IGB&SC research. Moreover, if an author has citation burst, which refers to a predominant raise of the citation frequency, his nodes would be indicated by a virticle line with an arrow. However, there is not such a line in this network, suggesting that the classic paper did not occur in our research domain from 2006 to 2016.

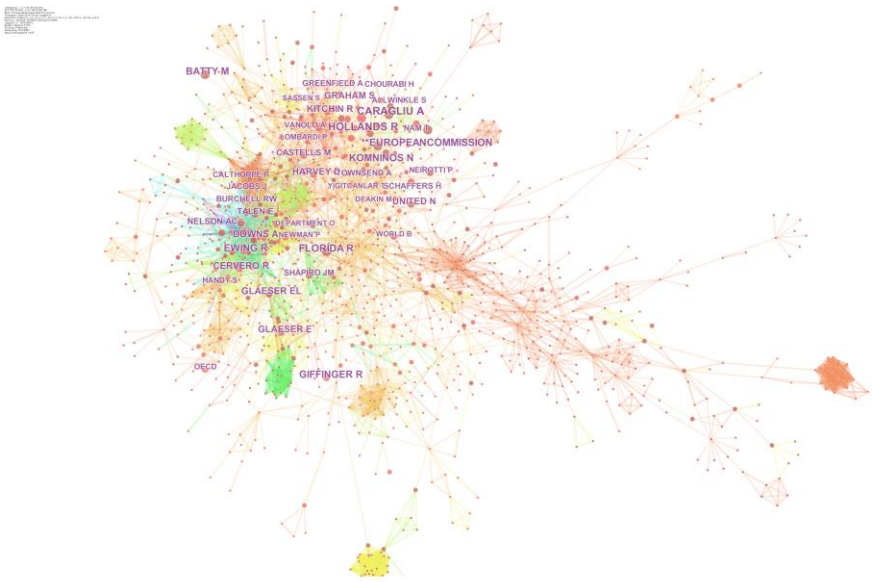

Fig. 2. Network of cited-author analysis, with 2,040 nodes and 5,809 links

2. Co-occurring Keyword Analysis

2.1. Network of Co-occurring Keywords

The keywords of an article provide information of its core content and help readers to gain an understanding of the development of research topics over time. As shown in Fig. 3, the network of co-occuring keywords has 468 nodes and 1,604 links. Of all the words, “smart city”, with a frequency of 232, “city” (154), “smart growth” (94), and “smart grid” (52) which relate to the topic of smart city, are high-frequency keywords; “sustainablity” (83), “suatainable development” (33), “energy efficiency” (27) and “renewable enengy” (25) emphasize the concept of green building and sustainable development; “system” (71), “model” (52)， “performance” (43), “impact” (40), “network” (30), “land use” (28) describe intelligent green building and smart city’s own research attributes; and “management” (56), “innovation” (43), “policy” (40), “design” (39), “governance” (30), “technology” (27) introduces several methods that can be adopted to advance the realization of intelligent green building and smart city.

According to the links between keywords, the focuses of research and the relationships among hot topics can also be identified. For instance, studies related to smart city and smart growth are highly associated with topics of sustainability, which confirm the relevance between our research topic-intelligent green building and smart city.

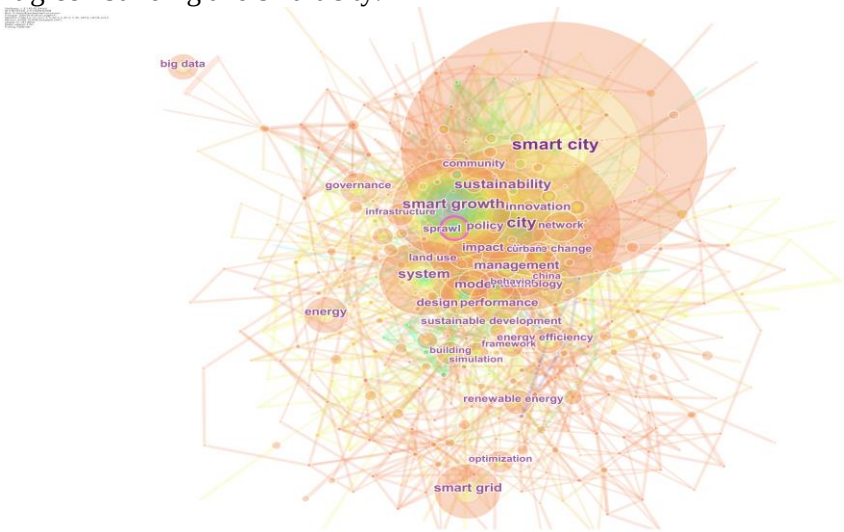

Fig. 3. Network of co-occuring keywords, with 468 nodes and 1,604 links

2.2. Co-occurring Keywords Timezone Analysis

A visualization timezone of our research, based on the keywords of each year, is shown in Fig. 4. In 2006, the major focuses of our target research concentrated on "smart growth" and "energy efficiency", then tended to "city", "urban", "sprawl" and "design" in 2007. In 2008, the research directions became various, researchers paied more attention to the "sustainability" of the city on one side, and simultaneously started to focus on more detailed areas of smart building and intelligent green building in the other side, such as its "model", "management", "system" and "performance". In 2009, two new keywords emerged, "community" and "behavior", which revealed that researchers began to concern people's life with regard to the development of intelligent green building and smart city.

At the beginning of the 21st century, with a high frequency, "smart city" turned to be the main focus of our research, along with the "policy", "land use", "energy", "building" and "impact", the prevalence of these keywords last two years, resulting in the absence of new keywords in 2011. In 2012, researchers kept a watchful eye on more newly-developing fields, such as "innovation", "simulation", "optimazation", "governace", "smart grid", "infrastructure" and "network", and this research tendency continued to the year 2013, keywords like "framework", "climate change", "renewable energy" and "technology" commenced. In 2014, China, as a country, became the keyword of our research, marking the moment when the research hotspot country shifted from America and Europe to China. Additionally, since 2015, "big data", as the new focus of researchers, has been popular for at least two years, as no new keyword with the same high frequency sprung in 2016.

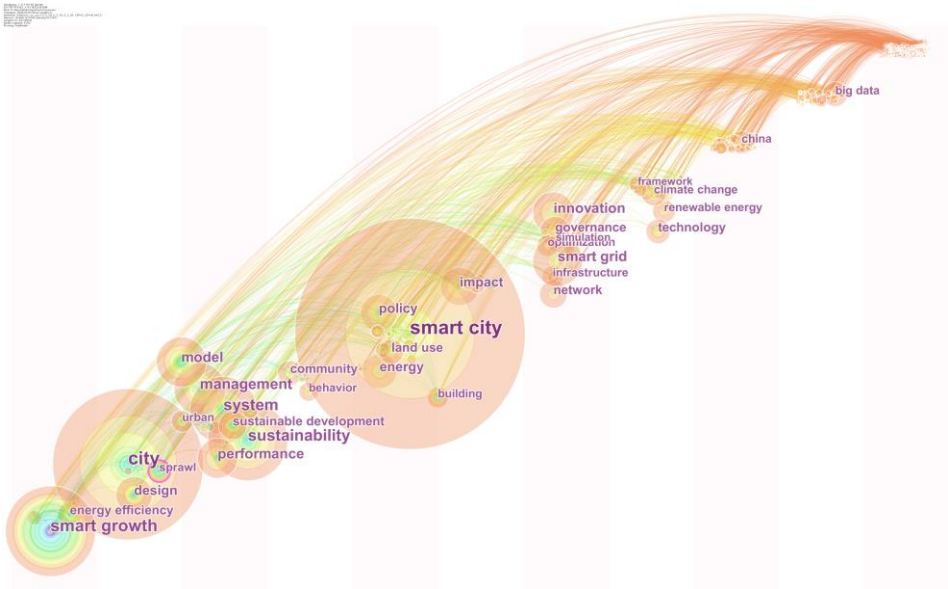

Fig. 4. Timezone of hot research topics according to co-occuring keywords

3. Document Co-citation Analysis

By using the Cited Reference function of Citespace software, references cited by published papers can be analyzed for the purpose of searching most popular cited documents, detecting recent active research areas and predicting future emerging trends.

3.1. Document Co-citation Network Visulization

Based on an analysis of 37,431 references cited in the 1,276 records retrived from WOS core collection, the document co-citation map together with the cluster view is presented in Fig. 5. Each node presents a document and is labeled with the author's name together with the publication year. To show their information more explicitly, the top 5 cited documents are summarized in Table 1, in terms of their citation frequency, author, publication year and document title.

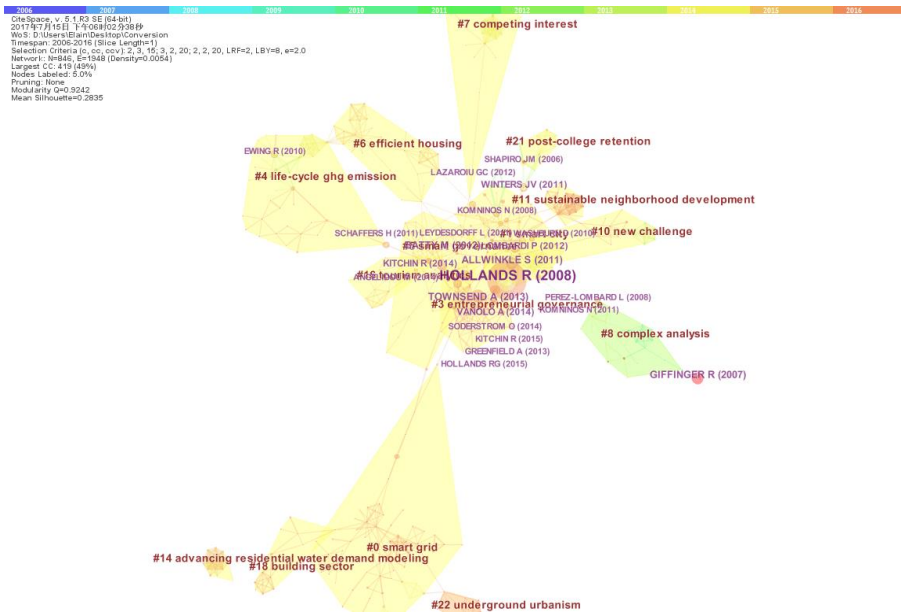

Fig. 5. Document co-citation map with the cluster view, with 846 nodes, 1,948 links and 216 clusters

Table 1 . The top 5 cited documents

No.	Frequency	Author	Year	Document title
1	67	Hollands R	2015	Critical interventions into the corporate smart city
2	40	Caragliu A	2011	Smart Cities in Europe
3	21	Neirotti P	2014	Current trends in Smart City initiatives: Some stylised facts
4	20	Allwinker S	2011	Creating Smart-er Cities: An Overview
5	20	Giffinger R	2007	Smart City Concepts: Chances and Risks of Enengy Efficient Urban Development

Hollands makes a two-fold critical intervention into the domain of corporate smart city model by looking at how people currently understand the smart city and critiques the growing trend towards entrepreneurial governance versions. Caragliu however proposes a focused and operational definition of present consistent evidence on the geography of smart cities in the EU27. Neirotti, on the other hand, provides with a comprehensive understanding of the notion of smart city through the elaboration of a taxonomy of pertinent application domains. While Allwinkle offers an overview of what it means for cities to be "smart", Giffinger lists chances and risks regarding energy efficient urban developments. All these five documents focus on smart city definition, indicating that the development of this domain is still in its primary stage and yet to be debeloped.

3.2. Bursts in the network of document co-citations

If the frequency of a term significantly increases in a short period of time, we can infer that this term represents a developing trend. Samely, a citation burst for a document indicates whether significant fluctuations in its citation frequency have occurred during a short period of time. Hence, citation burst is an indicator of a most active area of research, or an emerging trend[10]. In this study, documents and terms underwent significant burst from 2014-2016 are chosen to represent the current trends in intelligent green building and smart city research.

The hot topics and document citation bursts in this research over the past 11 years are summarized in Fig. 6. According to the time line, Fig. 6 illustrates the top 11 references with the strongest citation bursts. The first four documents which were most cited from 2007 to 2013 all focused on smart growth (Song, Downs, Ye, Handy 2005). In a similar period of time, since 2007 but more popular from 2010 to 2013, researchers also paied their attentions to the assessment of intelligent green building (Handy 2005; Chen 2006; Alware 2010; Glaeser 2011; Ewing 2010). However, from 2011 to 2014, the topic of Smart City started to become popular (Shapiro 2006), and in the past 3 years, Smart City has shown

significantly high burst strengths, which means it will be an active area and the emerging trend for further research.

Fig. 6. The top 11 references with the strongest citation bursts

CONCLUSION

Intelligent green building and smart city (IGB&SC) have been widely studied around the world and become research hotspot in recent years. This paper adopts a scientific visualization method to explore the knowlodge domain and emerging trend of IGB&SC development based on 1,276 papers published between 2006 and 2016 in the WOS core collection database. As a result, the co- author and cited-author analysis, co-occuring keywords analysis (normal network and timezone visualization) and document co-citation analysis (normal network and citation bursts) are applied.

With regard to the contributions made by the influential author identified in the co-author and cited-author analysis, Winters JV is the most productive author while Caragliu A is the most co-cited researcher. Moreover, based on the comparison of the most productive and most influential authors concluded from the analysis, we find out that almost no highly productive author have had the same high levels of influence in the field of IGB&SC. However, authors who have not produced large quantities of publications are more influential due to their high co-citation frequency.

High-frequency keywords are identified through the analysis of co-occurring keywords, and the results indicate that different focuses of IGB&SC research have been emerging continually from 2006 to 2016 in terms of smart growth, sustainability, smart city and big data.

Through the document co-citation analysis, the most highly cited articles are identified. Hollands's publication, which makes a two-fold critical intervention into the dominance of corporate smart city model, had the most cited records from 2006 to 2016. Moreover, the emerging trends that are evident from the bursts analysis in document co-citations in our target research can be concluded as smart growth, the assessment of intelligent green building and smart city.

The outcomes of this research are reached based the WOS core collection database, which includes the primary journals where IGB&SC papers are published. Hence, the bibliographic records analyzed in this paper represent enough and high-quailty body of researches which can accurately reflect the global development of IGB&SC research, although not every single publication is included. The results presented in this paper provide insights with regard to influential authors, keywords of focus, research hotspots and emerging trends in the field of IGB&SC. These are expected to benefit both practioners and academia for implementing theories into practice.

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