Case Study

Development Trend and Segmentation of the US Green Building Market: Corporate Perspective on Green Contractors and Design Firms

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Abstract: In the past decade, the architecture, engineering, and construction industry has witnessed increasing growth in the green building market and continues to expect a promising future. Although companies in the industry have played a significant role in developing the green building market, scarce studies have analyzed changes in the market from the perspectives of these corporations. Also, few studies classify green building companies by characteristics. To fill these gaps of knowledge, we explored the characteristics of the US green building market from a corporate perspective, specifically investigating green contractors and design firms. We first collected data of 464 top US green building companies identified by the *Engineering News-Record* over the past decade and explored the development trend of the green building market, based on the green revenue generated by these companies. We found that the general growth trend in the US green building market in the past decade could be divided into three stages: a rapid-growth stage (2000–2008), a steady-growth stage (2009–2013), and a maturity and transformation stage (2014–2016). We then categorized the 464 organizations into three groups with distinct characteristics by *k*-means cluster analysis techniques, including mature green building companies, sector-oriented green building companies, and primary-stage green building companies. This study provides the academic and practitioner communities with a holistic understanding of the development of the US green building market from the view of burgeoning companies. Corporate-level management systems and sustainable practices of the three clusters of green building companies also provide guidance for construction companies in the various stages of transformation towards sustainability to adopt different strategies. **DOI: 10.1061/(ASCE)CO.1943-7862.0001924.**

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Introduction

The architecture, engineering, and construction (AEC) industry is often criticized for its negative impact on the environment, including environmental pollution, waste of energy, and loss of biodiversity (Ahn et al. 2013). In this context, the industrywide green building movement has emerged over the past two decades. This movement is the response of the AEC industry to the environmental and resource impacts of the built environment (Kibert 2016). Various institutions proposed definitions of green buildings. For example, the World Green Building Council defined a green building as a building that reduces or eliminates the negative impacts and creates positive impacts on the environment in the life-cycle (USGBC 2016). Similarly, the US Green Building Council (USGBC) defined green buildings as "buildings that are designed, constructed, and operated to boost environmental, economic, health, and productivity performance over non-green buildings" (USGBC 2003). As a result, green buildings have become a promising pathway for the AEC industry to contribute to sustainable development (Darko and Chan 2016).

With the evaluation systems developed globally as a catalyst for green buildings, green buildings gradually became the mainstream in the industry (Lockwood 2006). Examples of assessment systems include Leadership in Energy and Environmental Design (LEED) in the US, the Building Research Establishment Environmental Assessment Method (BREEAM) in the UK, and the Green Star in Australia. A total of 493,733 are LEED-certified residential units and 1,162,762 are LEED-registered residential units around the world (USGBC 2019). In the World Green Building Trends 2018 report, almost half (47%) of industry respondents expected to transform the majority of their projects to green by the year 2021 (Buckley and Logan 2018). As green building projects expand their penetration in the industry, stakeholders like the government and legislature, contractors, design firms, consultancy agencies, developers/owners, and material suppliers have received benefits of reductions in energy consumption, financial profits, improved user experiences, and sustainability in this trend of green building development (Ma et al. 2017). The green building market is a complex business ecosystem comprising the previously mentioned standards, legislation, products (projects), and various stakeholders in the field of green buildings.

With the rapid development of the global green building market, relevant topics have received scholarly attention. Several researchers explored the development of the green building market. Although many previous studies investigated the development of the green building market from the perspective of green projects

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(Cidell 2009; Kaza et al. 2013) and the perspective of standards and legislation (Darko et al. 2017a; Zhang et al. 2017), scarce studies have explored the green building market from the perspective of building corporations. The green building market consists of a large number of firms moving toward sustainability. These firms, identified as green/sustainable building companies, have played important roles in market development (Chang et al. 2017). Among various types of companies in the market, each has its own interests, focusing on certain aspects of green building. For instance, developers aim to achieve profit maximization while owners focus on saving operational expenses (Chan et al. 2009). This study specifically focuses on green design firms and contractors in the green building industry.

Design firms and contractors play an essential role in the delivery of green building projects. As critical links among stakeholders (developers, owners, consultancy agencies, and government institutions) in the industry, design firms and contractors provide a more objective view of the green building market (Chan et al. 2009). Compared with other stakeholders who are not direct producers of green buildings such as financial institutions, design firms and contractors directly produce green buildings and thus the data of their business activity can more accurately reflect the market development trend of green buildings. Because further analysis on these two important stakeholders in the green building market is needed, in this study, we aimed to answer the following questions: From the perspective of green building companies (green design firms and contractors), how did the green building market develop and change over the past decade? What are the characteristics of these green building companies?

By taking the US green building market as an example, this study attempts to explore the development trend of the green building market from a corporate perspective and to identify characteristics of different types of green companies in the market. To achieve these objectives, we collected related data on 464 representative green companies (contractors and design firms) identified by the *Engineering News-Record* (ENR), and based on those data, we employed statistical analysis and *k*-means cluster analysis to investigate market-level trends and corresponding corporate-level characteristics. The findings may help stakeholders and academics better understand the development trend of the fast-growing US green building market, as well as provide valuable references for practitioners to develop sustainability strategies.

Literature Review

Drivers and Barriers of the Green Building Market

The green building market has grown rapidly in many countries around the world. Companies developed advanced technologies and novel products to meet increasing demands (Kibert 2016). Research on the green building market has been the focus of several streams of studies. One focus of this study is to investigate the drivers and barriers of green building development. Using surveys and interviews with key stakeholders in the green building market, prior studies identified many identifiable drivers and barriers across countries and categories in the development of sustainability in the industry (Bond 2010). For instance, Chan et al. (2009) investigated factors that drive the popularity of green buildings and the obstacles that hinder markets in Hong Kong and Singapore from the building designers' perspectives. Based on an industrywide survey, Liu et al. (2012) found that high fabrication costs in the design stage and cost control in the construction stage are two main obstacles to green building practices in China.

Despite the relatively high cost, green buildings are still in high demand in China with support and incentives from the government as the main drivers (Liu et al. 2012). With the systematic review of 42 empirical studies, Darko et al. (2017b) identified 64 drivers of green buildings that lie in the following five categories: external drivers, project-level drivers, corporate-level drivers, property-level drivers, and individual-level drivers. Among the literature reviewed by Darko et al. (2017b), government regulations and policies, energy conservation, and reduced whole lifecycle costs were three of the most commonly addressed drivers. Similarly, Ahn et al. (2013) and Olubunmi et al. (2016) examined the internal and external incentives of green buildings from various perspectives involving the environment, economy, and society.

To identify barriers, Darko and Chan (2017) conducted a thorough review of the related literature, and found that the top global barrier to the green building industry is lack of information, due to lack of education and research on green buildings, followed by the other barriers such as cost, lack of incentives/support, and lack of interest and demand. Hoffman and Henn (2008) indicated that people's unobservable psychological and social structure biases form barriers hindering the full adoption of green buildings. Previous studies provided valuable references for stakeholders in the green building market—industry practitioners, scholars, and policymakers—to better understand the influential features of green buildings and further promote green building markets.

Dynamics and Development of the Green Building Market

Apart from studies on the drivers and barriers impacting the green building market, the dynamics and the development of the green building market are also focuses of some prior studies. For instance, Ma and Cheng (2017) measured the size of the US green building market through the number of certified LEED projects and identified the numerical patterns of leading counties in the US local green building markets. Cidell and Cope (2014) shed light on the relationship between the number of green building policies and the number of registered green buildings by implementing logistic and linear regression in 664 cities in the US. Fuerst et al. (2014) also studied the green building market in 174 core-based statistical areas of the US and investigated factors that could boost the number of certified LEED projects. Linking the green building market and infrastructure construction, Kim and Cho (2014) investigated the impact of green building market growth on the infrastructure market and forecasted future trends concerning market values by analyzing carbon trading and renewable energy. Zhang et al. (2018) explored green building development in China based on star labeling projects from 2008 to 2016 and the development of assessment standards, stating that Chinese green building development remained in a critical period of maturity. A comprehensive post hoc analysis of 4021 LEED 2009 certified buildings in the US, Turkey, and Brazil showed performance benchmarks for each country (Wu et al. 2018). Prior studies not only indicated a close relationship between green building projects and the green building market, but also demonstrated the fundamental role and huge impact of green building standards/rating systems like LEED across the development of the green building market.

Stakeholders in the Green Building Market

The previously mentioned studies described factors impacting the green building market, as well as the dynamics and development of the market, and investigated green buildings at the market level. However, green buildings cannot be developed without the efforts

of various stakeholders engaged in this industry. Stakeholders in the green building market comprise internal stakeholders on the demand side (owners) and the supply side (contractors, design firms, and material suppliers), and external stakeholders on the private side (local landowners) and the public side (government regulatory agencies; Li et al. 2018). Bahadorestani et al. (2020) quantitatively developed a stakeholder-engagement plan and applied it in a green building project, demonstrating the effectiveness and flexibility of the developed matrix. Through social-network analysis, Yang et al. (2016) identified critical stakeholders and risks in green building development projects and found that in China, the government as an external stakeholder is the most fundamental driver of green buildings, whereas in Australia, internal stakeholders like building companies play a more critical role with self-motivation toward a better organizational reputation.

Among internal stakeholders, throughout the green building movement, some enterprises have identified sustainability as a key critical success factor and try to integrate sustainability into their corporate strategies for long-term prosperity (Lu and Zhang 2016). Several studies analyzed the sustainability practices of construction and building companies from various angles. For instance, Lu and Zhang (2016) developed a sustainable development framework for AEC organizations to promote sustainable construction. Ahn and Pearce (2007) collected data from 87 companies through a questionnaire to investigate contractor experiences, expectations, and perceptions associated with green buildings. Similarly, Ofori-Boadu et al. (2012) analyzed the LEED-project management practices implemented by six US contractors, based on structured case study interviews. Chang et al. (2017) proposed transition pathways toward higher sustainability levels for different groups of building companies by conducting an importance-performance analysis of critical sustainability aspects. Zuo et al. (2012) investigated the sustainability policy adopted by the top 50 international contractors listed by the ENR through a critical qualitative approach. Saleh and Froese (2018) studied the integration of green buildings in Canadian contractors from the company-management perspective by interviewing staff of four construction companies with rich experience in onsite practices of green building. To a certain extent, these studies revealed the sustainability aspects of various building companies in the green building market.

Research Gap

Even though recent studies enriched the understanding of the green building market, gaps in knowledge persist. First, many studies investigated the development/penetration of green buildings in the industry (i.e., how the green building market evolves and changes) from the perspective of green projects (Darko et al. 2017a, b; Fuerst et al. 2014; Ma and Cheng 2017) or the perspective of standards and regulations (Cidell and Cope 2014; Zhang et al. 2018). In contrast, few researchers analyzed changes in the development of the green building market from the perspective of building companies like green building contractors and green building design firms. Second, although researchers have conducted broad investigations on aspects of sustainability (e.g., strategies, practices, and perceptions) of various internal stakeholders in the industry (Lu and Zhang 2016; Ofori-Boadu et al. 2012), we did not find any studies that have classified the green building companies according to their characteristics. Thus, generalizable characteristics in different kinds of green building companies are lacking.

Some survey-based and interview-based studies on stakeholders in the green building market have potential inadequacy due to being overly qualitative and subjective (Li et al. 2018). A need persists for more quantitative and objective methods of analyzing the sustainable aspects of green building companies. By taking the US green building market as an example, in this study, we aim to explore the development trend of the US green building market from the corporate perspective and identified characteristics of different types of green building enterprises in the market.

Methodology

Data Collection and Processing

To analyze the green building market from a corporate perspective, we collected data on green enterprises from *the Top 100 Green Contractors* and *the Top 100 Green Design Firms* ranking lists released by the ENR in the past decade (2008–2017). Initiated in the 1970s, ENR ranks companies in specific market categories annually based on the prior year's revenue of these companies (ENR 2019). In recent years, researchers have employed and validated ENR ranking data, including Zhao et al. (2016), Zilke and Taylor (2014), Lu and Zhang (2016), and Wang et al. (2020). In particular, Lu (2014) conducted a holistic examination of 51 top international construction companies ranked by ENR and confirmed the reliability of ENR international construction company's data, stating that "researchers can use these data with a high level of confidence" (Lu 2014, p. 981). Lu's analysis reflected that the ENR ranking list data are of overall high quality and research feasibility.

Similar to other ranking lists on the ENR, *the Top 100 Green Contractors* and *the Top 100 Green Design Firms* lists are both based on companies' self-reported data, which in this case is their volume of sustainable and green projects. ENR ranks companies according to the revenue for construction or design services generated in the previous year from projects that have been registered with or certified by a third-party organization that sets standards for measuring a building's environmental impact (e.g., LEED; ENR 2014). Based on annual reports released by ENR, we collected information on these representative green building companies from the ENR top lists (2008–2017). The originally collected data includes the following features that relate to the sustainability performance of the company: (1) rank of the company (range from 1 to 100); (2) name of the company; (3) headquarter location of the company; (4) number of accredited staff in the company (ranging from 0 to 1,539); (5) total green revenue in the previous year (ranging from \$20.6 to \$5,701 million); (6) percentage of green revenue to total revenue (ranging from 3% to 100%); and (7) percentage of green revenue in different market sectors (adds up to 100%), namely retail/office, government office, education, healthcare, hotel, multiunit residential, entertainment/civic, miscellaneous buildings, and other markets (industrial process and pharmaceutical plants, food processing plants, manufacturing facilities, telecommunications facilities, infrastructure and cabling, towers and antennae, data centers, and web hotels) (ENR 2014).

After processing and reorganizing the data, we used 2,000 data points (10 years of the two top 100 lists) to calculate various indicators of the 464 green building companies (Table 1). We calculated all values based on the available data from the top lists. For instance, if one contractor only appeared on the top list a total of three times (3 years), we calculated the indicators (average values) based on the company's data in these 3 years. As shown in Table 1, six indicators of sustainability performance in green building companies derived from the original data extracted from ENR reports (2008–2017). The average rank of a company is the mean value of the green building company's rankings. The frequency is the count of the total times that the company has been listed on the ENR top

Table 1. Indicators of green companies

Number	Indicators	Meaning
1	Average rank (1–100)	The mean of the company's ranks
2	Frequency (1–10)	The frequency of the contractor on the top lists
3	Average green revenue	The mean of the company's total green revenue
4	Average percentage of green revenue to total revenue (0%–100%)	The mean of the company's percentage of green revenue to the total revenue
5	Average number of accredited staff	The mean of the company's accredited staff
6	Average market count (1–9)	The mean of the market count of the company, which is the number of the firm's green contracting markets, including retail/office, government office, education, health care, hotel, multiresidential, entertainment/civic and other markets

100 ranking lists throughout the past 10 years. The average rank and frequency represent the overall sustainability performance of green building companies. Higher average ranks and larger frequency counts indicate that the company performs better on sustainability. The same as the average green revenue, we calculated the average percentage of green revenue to total revenue, and the average number of accredited staff. For average market sector count, we calculated the mean value of all market sector counts in 10 years and got the average market sector count, which is an indicator of a company's coverage level in different green building market sectors. The higher the market sector count, the broader the market sectors in which the company delivered green building projects. These indicators are key factors of green building companies, based on the original data reported by ENR, and we used them as variables in cluster analysis to further analyze the characteristics of different groups of companies.

Descriptive Analysis

Descriptive statistics are capable of describing a large amount of data sensibly (Jaggi 2012). We calculated the sum of the top 100 contractors and 100 green design firms' green contracting total annual revenue as representative of the year's total green construction revenue. Researchers offered sufficient precedent for setting the revenue reported by ENR top lists as representative of market development (Kim and Reinschmidt 2012; Lu et al. 2009; Vashani et al. 2016). Specifically, Vashani et al. (2016) investigated the development trends of the design-build market based on revenue data from the 2003–2013 ENR top design-build firms lists. Factors that affect the total green revenue varies (e.g., standards, government legislations, and other stakeholders); thus, we analyzed the revenue data and the original reports released by ENR, which contained reviews and discussion of green building market development from experts and industry practitioners. The ENR annual reports also describe other factors that could affect a company's perception of green buildings and the company's sustainability strategies (e.g., their annual budget of green building projects), which provide sufficient information for us to investigate the overall development trends in the green building market.

Apart from the total revenue, we also investigated the percentage of the five market sectors that accounted for the highest annual share of green contracting: commercial offices, education, healthcare, government offices, and multiunit residential. We calculated the annual share of a certain market sector by summing each company's green revenue in that market sector (company's total green revenue times the percentage of green revenue in the market sector) divided by total annual green revenue. Based on the data released in ENR reports, the selected five market sectors continuously ranked top in the annual share, indicating their significant impact on the market compared with other market sectors (ENR 2010, 2012, 2014). The significant change in these market sectors' annual share also revealed variation in green building market development trends, further demonstrated in the next section. The original data in a certain year indicates the market development of the previous year because rankings are based on the companies' green revenue of the previous year. For example, the 2008–2017 reported annual revenue of the top 100 green contractors indicated the 2007–2016 development trend of the green building market. We produced histograms and line charts of the resulting values to demonstrate green building market development trends.

As we analyzed development trends in the green building market based on annual green revenues from ENR data, we considered variations in LEED standards. In the United States, LEED is one of the most adopted rating systems (Langar et al. 2013), evolving from older versions 2.0 and 2.2, to the latest 4.0. With its continuous improvement, LEED outperforms other green building accreditation standards (e.g., Green Globes and ENERGY STAR) in evaluation scope and professional regulation, and earns the title of "the most prominent sustainable building certification system for developers, tenants, and real estate investors" (Blumberg 2012, p. 25). Different versions of LEED could make a great difference to the green building market and stakeholders in the industry by modifying LEED certification standards and processes (Rastogi et al. 2017). Thus, we considered these variations in our analysis. Integrating green annual revenue with the advancement of various LEED versions, we divided the development trend of the green building market in the past decade into stages, based on descriptive statistics, and then analyzed the characteristics of each stage.

Cluster Analysis

Contractors and design firms collected from the ENR top 100 ranking lists showed different sustainability performances. We applied a data-mining technique—cluster analysis—to classify these companies according to the integrated information. Cluster analysis classifies groups by the characteristics of the sample data without the need to know the structure of the group in advance (Wilmink and Uytterschaut 1984). Using cluster analysis, we divided instances with maximum internal homogeneity and maximum external heterogeneity (Carvalho et al. 2015) to differentiate companies using k-means cluster analysis. As one of the most commonly used unsupervised machine-learning techniques, k-means cluster analysis adopts iterative partitioning algorithms, enabling the analysis of large data sets and skirting drawbacks of hierarchical agglomerative methods (Jovanovic and MacDonald 2000). Following the comparative analysis of company information, we selected, standardized, and applied the k-means cluster analysis.

With the identified clusters, we conducted comparative case studies. We analyzed characteristics and differences among groups by comparing clustering variables' mean values in individual clusters. Based on the mean values of the variables in each cluster, we chose typical enterprises in each cluster with representative

characteristics of the clustered companies. We then collected the green building practices and performances of typical companies from the companies' official websites and annual reports. Of companies on the ENR *the Top Green Contractors* list, 95% have at least one page on their websites introducing their green building practices, yielding important information for analysis (Fernández-Solís et al. 2018). Using the collected information, we were able to analyze these enterprises' important sustainability strategies in the development of green building companies.

Development Trends of Different Green Building Markets

Based on the sum of the top 100 green companies' annual revenue and the percentage of five market sectors that account for the highest annual share of green contracting (commercial offices, education, healthcare, government offices, and multiunit residential), Figs. 1 and 2 illustrate green building market development trends, showing development patterns from the perspectives of design

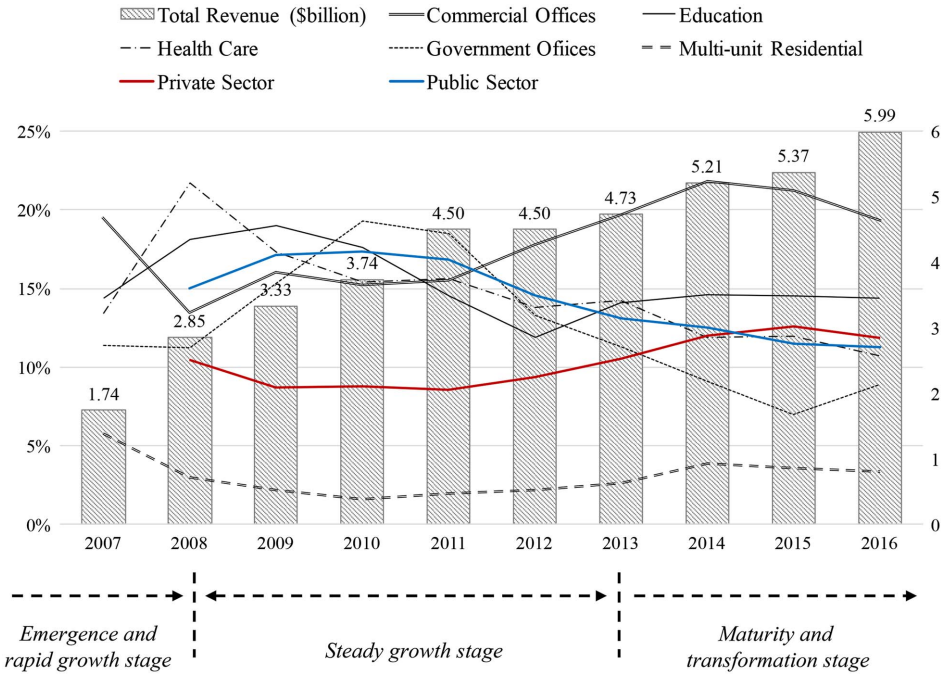

Fig. 1. Green building market development trend (design firms).

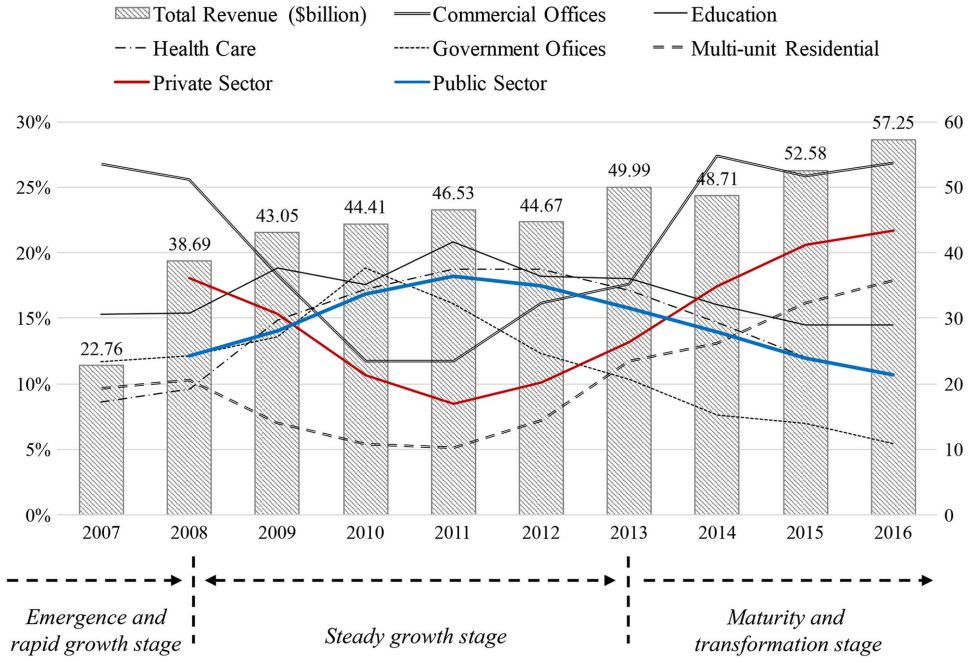

Fig. 2. Green building market development trend (contractors).

firms and contractors. In general, the green building market has grown in the past decade, whereas the market share of different market sectors has fluctuated over the same period. The green revenue generated by contractors is about 10 times that of design firms (Figs. 1 and 2). Fig. 2 shows two notable change points in market share by sector, namely 2008 and 2014. Figs. 1 and 2 show the overall development trend of the private sectors (commercial offices and multiunit residential) and the public sectors (education, healthcare, and government offices). Based on our analysis, the 2008 global financial crisis and the 2009 modified LEED standards may have influenced market changes in 2008, and the new LEED version 4.0, launched in November of 2013, may be the cause of the change in 2014. Considering the effects of the real estate market, variations in LEED versions, and the hysteresis of these effects on the market, we divided the development of the green building market in the past decade into three stages: emergence and rapid growth stage (2000–2008), steady growth stage (2009–2013), and maturity and transformation stage (2014–2016).

Emergence and Rapid Growth Stage (2000–2008)

Since the USGBC officially launched LEED version 2.0 in 2000, the green building industry changed gradually from 2000 to 2008. Design firms' and contractors' total revenue grew swiftly from 2007 to 2008, and commercial offices accounted for approximately one-quarter of the green building market (Figs. 1 and 2). The introduction of LEED version 2.0 enabled the market to have an official, reliable green building rating standard, stimulating the emergence of the green building market (Richards 2012). At the stage, the need for LEED certifications targeting many specific market sectors arose, including private sectors (commercial offices and multiunit residential; Figs. 1 and 2) and public sectors (education, healthcare, and government offices; Figs. 1 and 2). As shown, the market share of the education and healthcare markets rose sharply among design firms and increased smoothly among contractors. However, the 2008 global financial crisis led by the collapse of the US housing bubble directly impacted the green building market. The market share of the private sectors dropped from 2007 to 2008 among design firms and contractors.

At the same time, the soft costs and hard costs of building green projects decreased as the market developed. During the emergence stage, some companies considered green buildings to be expensive luxury goods with high initial costs (Li et al. 2014). Hard costs are fundamental to construction (e.g., construction work, materials, and labor); soft costs are other nonphysical expenses for design and certification services (e.g., fees by the design team or expenses of energy modeling for the project; Nurul Zahirah and Abidin 2012). From design firms' perspectives, designers gradually accumulated experience in green buildings, reducing the cost of designing green projects (soft costs). From the contractors' perspective, the cost of completing green construction projects gradually decreased for two main reasons. First, as contractors gained familiarity with green construction projects, they gradually developed their own green construction vendor pool and no longer needed to spend additional funds on the soft costs of consulting and market research (ENR 2008). In addition, the industrialization of materials and facilities required for green construction also reduced the hard costs of building green projects (ENR 2008).

Steady Growth Stage (2009–2013)

The green building market continued to grow steadily from 2009 to 2013. Figs. 1 and 2 show that, at this stage, green building companies' total annual revenue reflected the fluctuating growth trend in the market (bar chart), whereas the market share of different market sectors underwent great changes (line chart). In 2009, the US Green Building Council introduced a revised standard for green construction ratings, LEED 2009 (previously version 3.0). LEED 2009 focused more on the efficiency of resources and energy of new green buildings. The Water Efficiency and Energy and Atmosphere categories gained higher weights in the rating scheme (Langar et al. 2013).

Owners began to pay greater attention to the reduction of operating costs and expressed a much more cautious attitude toward green projects (ENR 2010), largely due to the global financial crisis (GFC) of 2008. A new trend emerged in the green building market. Unlike judging green buildings simply by corporate-social-responsibility values in the rapid growth stage, industry stakeholders started to apply a more holistic systems approach to green buildings after the GFC (Christensen 2017). The positive impact of the GFC on the green building market lies in risk management. For developers, investments in sustainable buildings reduced risk compared with traditional buildings because the buyers were more interested in green buildings with the benefits of operational cost reduction (Nistorescu and Ploscaru 2010). The change in the market also arose as a result of changes in the annual share of various market sectors. Affected by the GFC, the market share of commercial offices and multiunit residential (private sector) in the green building market dropped considerably and did not recover until 2012. However, the market share of government offices, education, and healthcare (public sectors) reached a peak during this period (Figs. 1 and 2). Due to the depressed market in the private sector, federal and state governments proposed mandatory requirements of green building standards for public construction projects by legislation, promoting the green building market in the public sector and stimulating the market in the private sector (ENR 2010). The market share in the public-sector rose from 2009 to 2011 and started to decline from 2012 with the gradual recovery of the private-sector market (Fig. 2).

Maturity and Transformation Stage (2014–2016)

The critical transformation at this stage was the market's change in attitude toward LEED standards. Some enterprises resisted LEED version 4.0, launched by the USGBC in 2013. LEED version 4.0 set a higher standard on the well-being and health of building residents, resulting in a higher standard in construction materials. Some chemical raw materials (like vinyl), originally widely used in the industry, were regarded as harmful to the human body and prohibited from use in the new standard (ENR 2014). The prohibition led to a huge rise in green construction material costs. Therefore, many stakeholders acted, lobbying lawmakers, and choosing other standards to prevent the implementation of the new standards.

Facing industry opposition, the USGBC postponed the official implementation of LEED version 4.0 to 2016. The impact of LEED version 4.0 on the green building market emerged as a fluctuation in the green building companies' total annual revenue from 2014 to 2016 (Figs. 1 and 2). Contractors' revenues dropped from $49.99 billion in 2013 to $48.71 billion in 2014. Design firms' and contractors' revenues both increased rapidly from 2015 to 2016 because enterprises in the industry rushed to gain LEED certification before the implementation of LEED version 4.0 to avoid increased green construction costs under the new standards. From the contractors' perspective, the commercial office market share returned to its peak before the GFC, and the multiunit residential market share grew to 17.9% in 2016 (Fig. 2). From the design firms' perspective, although the commercial office market share demonstrated the same growth pattern as contractors, the multiunit

residential market share remained at a relatively low percentage. The market share in the public sector (education, healthcare, and government offices) continued to decline among design firms and contractors in this period. From an external perspective, the rise of the private sector in the green building market accounted for its dramatic increase in market share and the inevitable decline of market share in other sectors. Although the market share in education and healthcare declined during this period, the green revenue of these two sectors was actually increasing, indicating that the green building market in these two sectors was still developing, albeit more slowly than the commercial or multiunit residential sectors. From the internal perspective, some government institutions gradually changed their requirements on green building certification, with a commensurate decline in revenue calculated based on green building projects in the government-offices sector. The US Department of Defense provides an example. Originally, all federal building projects were required to obtain LEED Gold-level certification. However, starting from 2012, the minimum requirement changed to LEED Silver, and the department changed from taking LEED as the only assessment to also using the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' Standard 189.1, which also covers the design of high-performance sustainable buildings (ENR 2012).

Cluster Analysis of Green Building Companies

Cluster Selection

We conducted a k-means cluster analysis to classify the 464 green building companies collected from the ENR top lists (2008–2017). We chose four z-score standardized variables (average rank, frequency, the average percentage of green revenue to total revenue, and average market count) as clustering variables. The number of clusters needs to be specified at the start of the k-means clustering procedure (Dikmen et al. 2009). To determine the possible range of the k for k-means clustering, we used the most traditional and widely used method, the elbow method. By calculating the within-cluster sum of squared errors (SSE) for different values of k, we plotted a line chart of SSE versus k, then identified the elbow where, for k, the SSE dropped dramatically then reached a plateau when the k increased further (Kodinariya and Makwana 2013).

Based on the elbow method, we identified that the elbow area is between three and five; thus, the number of clusters was determined as the range between three and five. We attempted three-cluster, four-cluster, and five-cluster solutions ($k = 3, 4, 5$). Judging from two criteria—maximum internal homogeneity and external heterogeneity, and parsimonious explanations (Chang et al. 2016)—the three-cluster solution outperformed the other two solutions. Regarding the first criterion, the maximum internal homogeneity referenced the SSEs of different clusters, and clearly, the five-cluster solution had the lowest SSE. However, when we tested the maximum external heterogeneity, we used the Bonferroni test of ANOVA analysis and found that the three-cluster solution performed best. The Bonferroni test is a multiple comparison test that shows the statistical significance of the dependent variables.

In Table 2 we recorded the groups (p-value) that were not statistically significant (the significance level of the mean difference is more than .05) in the four variables. In cluster analysis, groups are the clusters automatically generated by the used algorithm, namely the k-means algorithm in this study, when the number of clusters (k) is set. If the significance level of the mean difference between two groups on a specific variable is more than .05, it means that in terms of that variable, the two groups cannot be distinguished from each other. For example, in the four-cluster solution, the clustered Groups 1 and 2 are not statistically significantly different in variables average rank and frequency (Table 2), which indicates that the discrimination of two groups on these variables is low. Table 2 indicates that compared with the other two solutions, the three-cluster solution outperforms in maximum external heterogeneity. Regarding the second criterion, the three-cluster result shows more distinctive characteristics compared with the other two, satisfying the requirement of parsimonious explanations. Based on Table 2, the number of statistically insignificant pairs in the four-cluster and five-cluster solutions indicates these two cluster solutions don't align with the parsimonious-explanations criteria. Thus, we chose the three-cluster solution ($k = 3$) as our final choice.

Segmentations of US Green Building Companies

Based on the three-cluster solution, we divided the 464 green building companies collected from the ENR top 100 ranking lists into the three segments of mature green companies (Cluster 1), sector-oriented green companies (Cluster 2), and primary-stage green companies (Cluster 3). Figs. 3 and 4 illustrate the cluster distribution in each variable, respectively. We created Figs. 3 and 4 using IBM SPSS software, based on the compiled data of green building companies. Fig. 3 indicates the distribution of different clusters of companies in each variable, with multiple extreme

Table 2. ANOVA analysis result (Bonferroni test) of three different cluster solutions: statistically insignificant variable groups

Variables	Three-cluster ($k = 3$)	Four-cluster ($k = 4$)	Five-cluster ($k = 5$)
Average rank	—[a]	0.732 (Group 1–Group 2)[c]	1.000 (Group 2–Group 3)[c] (Group 3–Group 4)[c] 0.463 (group 2–group 4)[c]
Frequency	0.085 (Group 1–Group 2)[b]	1.000 (Group 1–Group 2)[c]	0.505 (Group 1–Group 2)[c] 1.000 (Group 2–Group 3)[c]
Average percentage of green revenue to total revenue	—[a]	—[a]	0.064 (Group 1–Group 2)[b] 0.485 (Group 2–Group 4)[c] 0.141 (Group 2–Group 5)[c] 1.000 (Group 4–Group 5)[c]
Average market sector count	—[a]	1.000 (Group 1–Group 3)[c] 1.000 (Group 2–Group 4)[c]	1.000 (Group 1–Group 3)[c] 0.083 (Group 2–Group 5)[b]

[a]Among the instances in these two groups, p-value < 0.05.
[b]Among the instances in these two groups, 0.05 < p-value < 0.1.
[c]Among the instances in these two groups, p-value > 0.1.

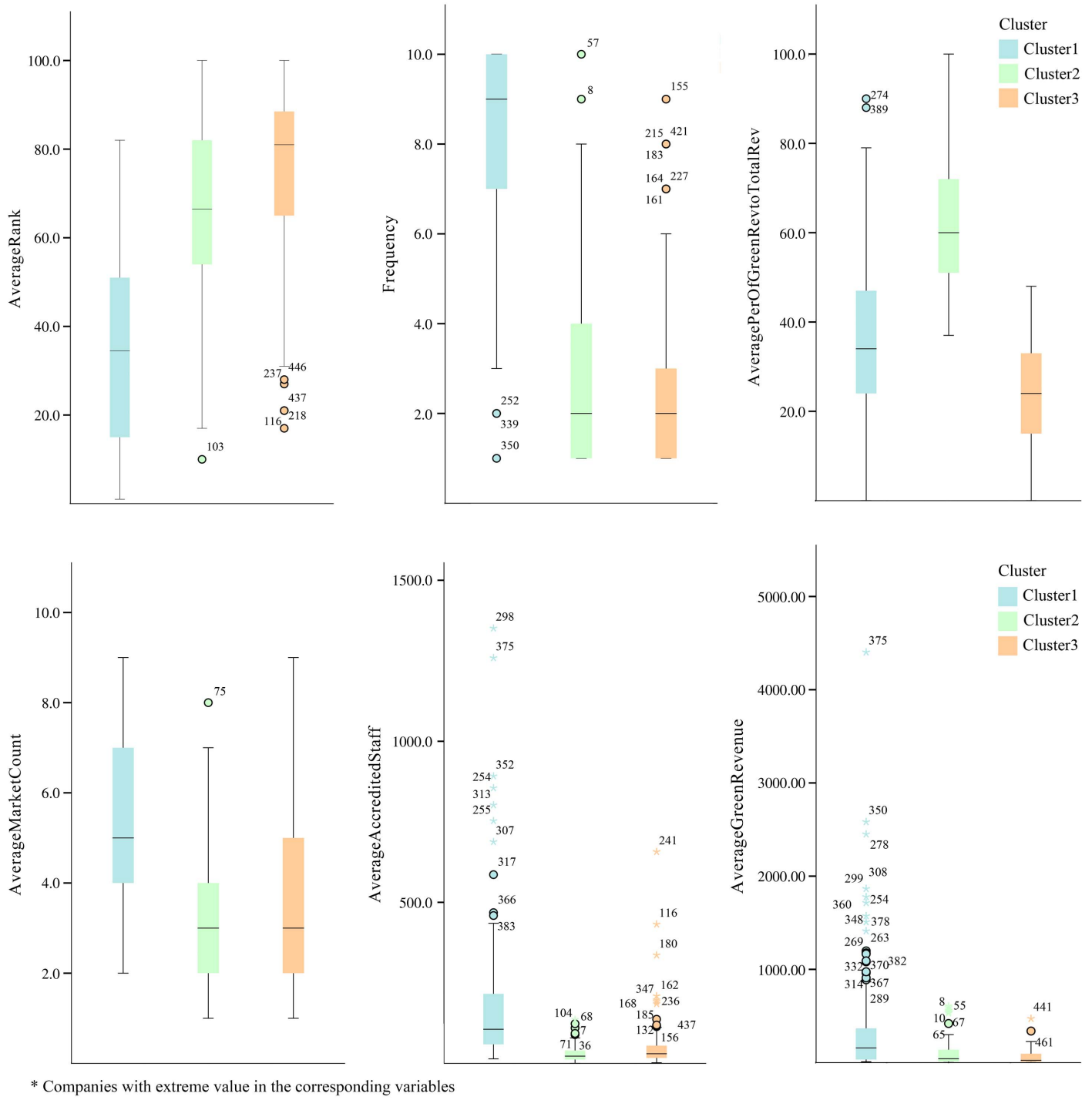

Fig. 3. Cluster distribution in six variables.

instances in average accredited staffs and average green revenues. The number of these extreme instances in Fig. 3 is the ID assigned to the company in alphabetical order. These extreme cases are typical or outstanding companies in the cluster and cannot be removed as noise. As a supplementary illustration of the clusters in Fig. 3, Fig. 4 reveals the distribution of clustering variables for each cluster, and the values in the blocks are mean values of variables in specific clusters. The light area in the blocks stands for the overall distribution (all companies) of the clustering variables and the dark area stands for the distribution of the clustering variable in a specific cluster. For example, the top left block indicates that most of the companies in Cluster 1 have relatively high average ranks. We further analyze these two figures in the subsequent sections.

Mature Green Companies (Cluster 1)

Cluster 1 has 140 companies designated as mature green companies, accounting for 30.2% of the total. Green building companies in this cluster are large-scale enterprises with strong competitiveness and extensive experience in the green building market. High average rank and high frequency suggest companies in this cluster often receive high rankings in the ENR top 100 ranking lists, which means these companies could gain higher annual revenue from

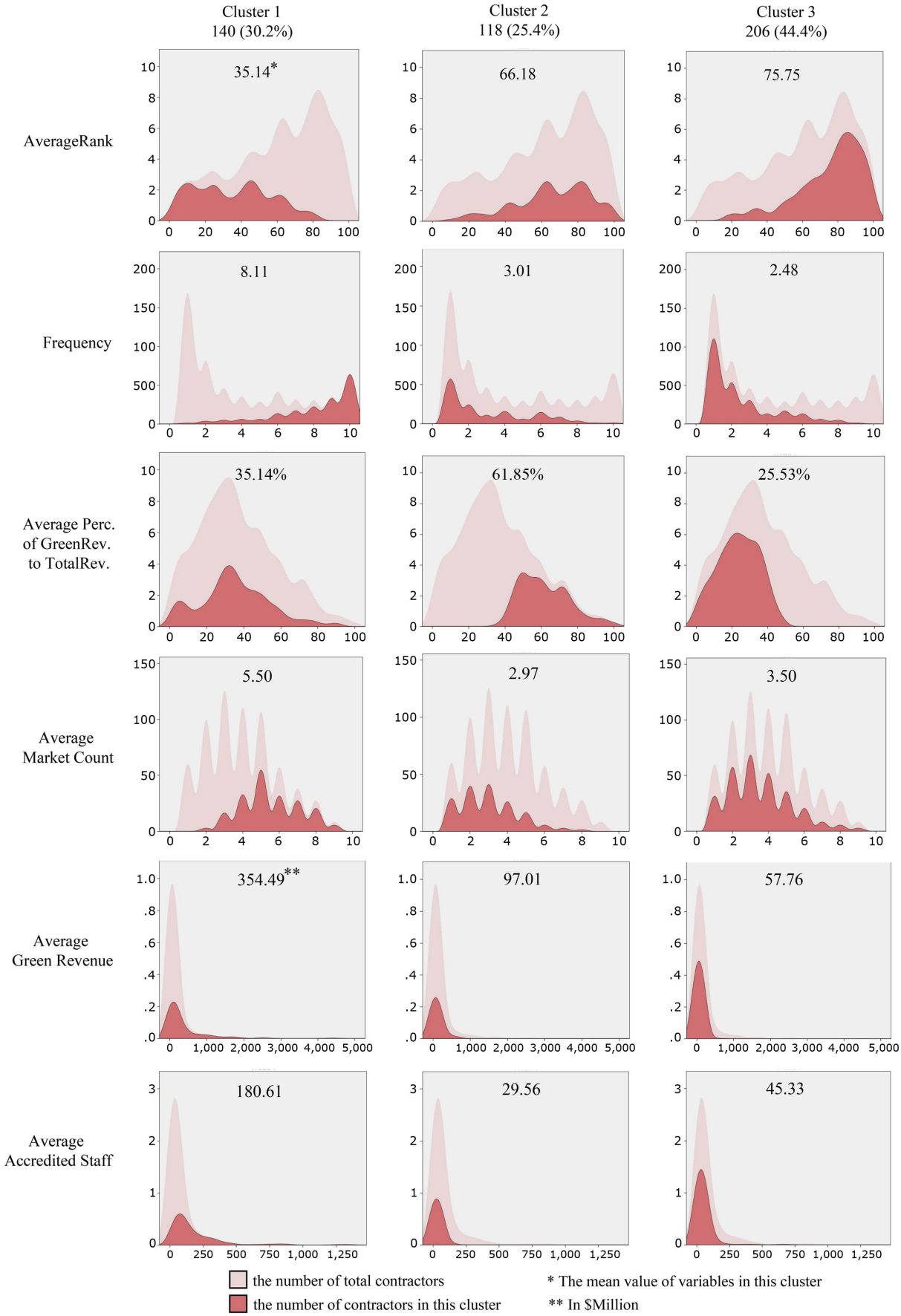

Fig. 4. Clustering variables' distributions for each cluster.

green construction projects compared with other companies (Figs. 3 and 4). Mature green building companies can integrate sustainability into their projects at the early stage of the market development, accumulating rich experience and expanding markets. Mature green building companies can also establish their own standards, management processes, and databases dedicated to green construction projects.

Consider Turner Construction Company as an example. Turner Construction Company ranked first in the ENR top 100 green contractors ranking lists from 2008 to 2017. Turner's annual green revenue is generally in a growing trend, consistent with the development trend of the green building market [Fig. 5(a)]. In addition, during the transformation stage, when LEED version 4.0 was launched in 2013, Turner's green revenue was fluctuating, similar to the patterns of all contractors (Figs. 3 and 4). The percentage of green revenue to total revenue and the number of accredited staff in Turner rose markedly in the rapid-growth stage of the green building market (before 2009), then fluctuated across stable values in the maturity stage (2014–2016). Turner integrates sustainable concepts into its daily corporate activities, such as training and encouraging employees to acquire LEED accredited professional credentials, advancing LEED certification in the company's projects, and evaluating the performance of green projects built by the company. Additionally, Turner is concerned about the latest development in the green building market, publishing the biennial *Green Market Barometer* to reveal the latest developments.

Another typical company in this cluster is the architectural design company, Gensler. For 10 consecutive years, Gensler has been ranked high among the top 100 green design firms, with an average ranking of second place and an average 56% of green revenue to total revenue [Fig. 5(b)]. The company's annual green revenue increased from $126 million in 2008 to $894 million in 2017 and the number of accredited staff in Gensler has also been steadily growing from 708 in 2008 to 1,646 in 2017. Gensler has popularized the concept of sustainable design in their projects. Gensler has designed more than 700 green building projects certified by the

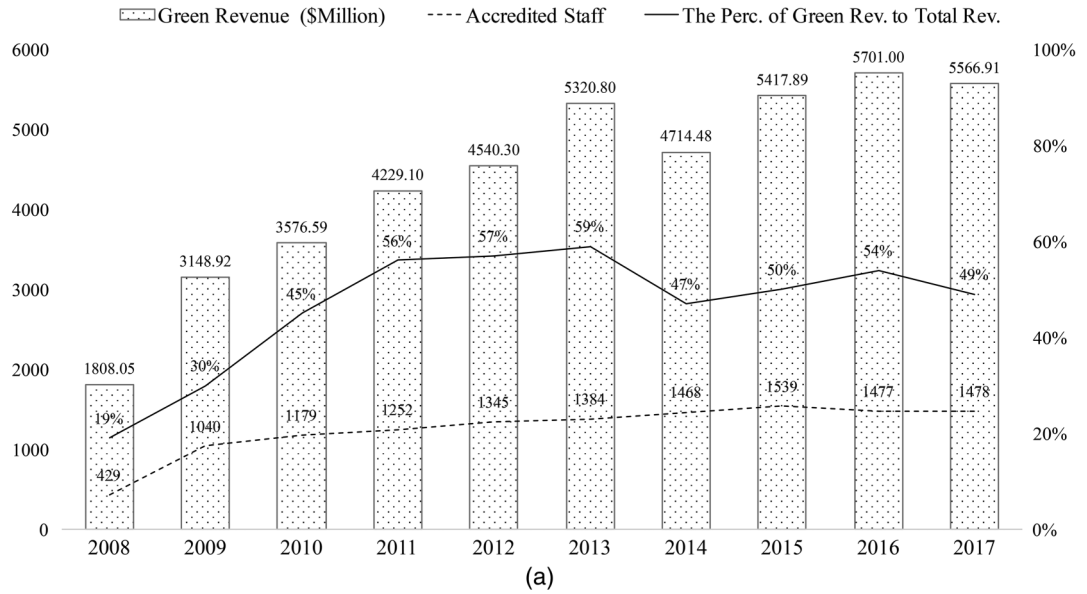

Fig. 5. Development trend of typical green companies in Cluster 1: (a) typical green contractor; and (b) typical green design firm.

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US Green Building Council. Similar to Turner, Gensler publishes annual reports, *Impact by Design*, to assess its corporate sustainability strategy and impact.

Sector-Oriented Green Companies (Cluster 2)

Sector-oriented green companies account for 25.4% of all green building companies, which is the smallest group among the three clusters. The two distinctive characteristics of companies in this cluster are the high average percentage of green revenue to total revenue and the low average market-sector count (Figs. 3 and 4). For companies in this cluster, 61.85% of total revenue was generated from green building projects, which means these companies not only have rich experience in delivering sustainable projects, but also consider green buildings their main business as a corporate strategy. The low average market-sector count indicates these companies focus their market occupancy in two or three specific market sectors. Compared with mature green companies (Cluster 1), average green revenue and average number of accredited staff in these companies are relatively lower, indicating that sector-oriented green companies are smaller but more concentrated than mature green companies. We assume that because sector-oriented companies generate green revenue from specific market sectors, their annual green revenue would be easily affected by the market share of that sector, further validated in the following case studies.

Dore & Whittier Architects. (hereafter D&W), based in New England, is a typical case in this cluster [Fig. 6(a)]. During the 3 years when D&W was on the top 100 ranking lists (2014–2016), the average percentage of green revenue to total revenue of the company was as high as 72%. The company's official website states they are very experienced in building LEED-certified educational projects. Most school projects that the company designed gained LEED Gold certifications, like Newton North High School (2015, LEED Gold) or Rockland Public School (2012, LEED Gold). Harper Construction Company is another case in this cluster. Harper has a high average percentage of green revenue to total revenue (83%) and low average market count (government offices,

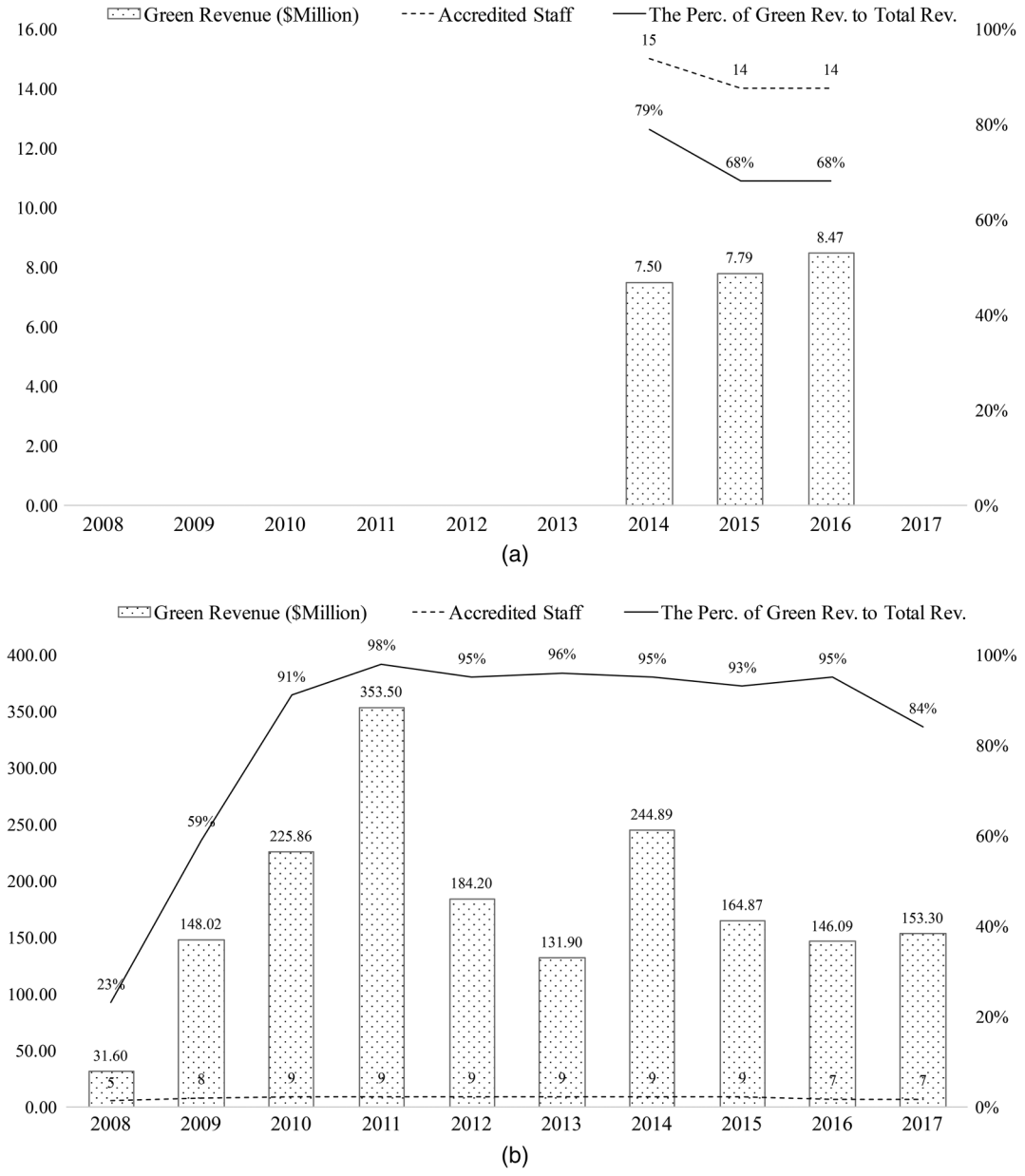

Fig. 6. Development trend of typical green companies in Cluster 2: (a) typical green design firm; and (b) typical green contractor.

education, and multiunit residential). Comparing Harper's development trend and the development trend of the market share of government offices, similar patterns emerged [Figs. 1 and 6(b)]. Harper's green construction revenue grew rapidly until it reached a peak in 2010, then dropped dramatically from 2010 to 2012, which is the same development pattern as the market share of government offices between 2007 and 2012. Harper relies heavily on the green government-offices market sector and suffers greatly from the decline of this market. Harper's case implies that the advantage of sector-oriented green building companies could also be its disadvantage. Concentration in one or two specific green building market sectors could bring these companies a market advantage in the accumulation of experience; however, it could also lead the companies' high sensitivity to the market environment.

Primary-Stage Green Companies (Cluster 3)

Cluster 3 contains 206 primary-stage green companies, accounting for the largest proportion of the total. The variables in Cluster 3 all have low values among the three clusters (Figs. 3 and 4). Of green building companies in this cluster, 91 have been on the ENR top 100 green contractor ranking lists only once and 160 companies been ranked three times or less. The low average rank in this cluster is 75.75 and the low average percentage of green revenue to total revenue is 25.53%, suggesting these medium-sized companies are still at a preliminary stage in the pursuit of sustainability.

We divided companies in this cluster into two categories. First, companies that made revenue from certain large-scale green construction projects and did not continue to apply sustainability in other projects only appear once or twice on the lists. Others entered the green building market in recent years and are still accumulating experience in green construction projects. The latter has a clear recognition of the future trend of the green building market and plan well for future development in the market. XL Construction Corporation is a typical case. XL Construction was on the 2016 and 2017 top 100 green contractors ranking lists with an average rank of 77. According to the company's website, XL Construction has already participated in more than 60 LEED projects and will participate in more green construction projects in the future. Epstein Uhen Architects (hereafter EUA) is another example. Green revenue accounted for 12% of total company revenue, and green projects were mostly medium-sized office or community projects. Although the company is still accumulating experiences of green building projects, EUA has begun to make a sustainable transformation through organizational restructuring, and the company has set up a green building committee to guide the company's sustainable development in the competitive market. The XL Construction and EUA examples show that some primary medium-sized green building companies are still in a rapid-growth stage.

Discussion and Conclusion

This study contributes to the green building market body of knowledge by (1) analyzing green building market development from the corporate perspective based on data (total annual green revenue) of representative green contractors and green design firms to reveal changes and different stages of market development trends; and (2) classifying green building companies by *k*-means clustering techniques and case studies to uncover distinct characteristics of groups of green building companies with different sustainability performances. These contributions can help academics and industry stakeholders better understand the overall development trend of the market and how different market sectors change in development trends. Additionally, findings on sustainable practices and strategies conducted by different clusters of green building companies can help green building practitioners build company sustainability strategies, based on market development and their company's situation.

Compiling the 464 representative green building companies in the industry based on the ENR top 100 green contractors and top 100 green design firms from 2008 to 2017, the analysis of the total revenue of the top 100 green companies depicts a general growing trend of the US green building market. Further investigation of changes in the annual share of different market sectors and the evolution of different versions of LEED standards reveals the three stages of market development. In the emergence and rapid growth stage (2000–2008), the market grew at a rapid pace with the launch of LEED version 2.0 in 2000, which provided an official green building standard for the market as a reference. The annual share of market sectors changed dramatically in the steady-growth stage (2009–2013). The share of private-sector projects like commercial offices and multiunit residential work declined at the beginning of this stage, likely attributable to the global financial crisis; then, the private sectors gradually recovered, starting from 2012. In contrast, the annual share in the public sectors, including education, healthcare, and government offices, reached a peak in this period with incentives from government policies and regulations. In the maturity and transformation stage (2014–2016), LEED version 4.0 set a higher standard on the well-being and health of building residents and stakeholders in the industry started to take a more holistic and systematic view toward green buildings.

Segmentation of representative green building companies through a data-mining technique namely the *k*-means clustering determined which companies shared similar characteristics in the market. Mature green companies (Cluster 1) have gained rich experience and strong competitiveness in the green building market. Companies in the industry may reference the management strategies of mature green companies like the green construction information system (e.g., green building subcontractor's vendor pool), green building professionalism development scheme, and organization structure for the green building market. Sector-oriented companies (Cluster 2) treat green building projects as their business emphasis, and these companies primarily focus on specific market sectors. Companies with the same features should be aware that the focus of the market sector could not only be beneficial for their market penetration but also become potential risks for the company, with a high sensitivity to sector market turmoil. The primary-stage companies (Cluster 3) are still unstable on the top green building company lists. Some companies in this cluster have just stepped into the green building market and show promising future development possibilities, which needs to be investigated in future research.

In this study we worked to discern the development trend of the green building market from the corporate perspective and to explore the characteristics of green building companies in the industry. Previous studies of the green building market assessed the perspective of projects (Cidell 2009; Ma and Cheng 2017) and standards (Cidell and Cope 2014). The findings from this study filled the gap of limited research investigating the market development from the perspective of building companies in the industry. Different from most previous studies investigating corporations and stakeholders in the green building market with subjective information from participants through surveys, questionnaires, and interviews (Chang et al. 2017; Ofori-Boadu et al. 2012), this study combined an objective data-mining technique and case study, revealing characteristics of different groups of green building companies. The methodology used in this study can be implemented in future research of other stakeholders in the green building market, and clusters of companies identified in this study may guide

companies in different development stages with different characteristics to build sustainable strategies.

Although this research revealed a more nuanced understanding of the US green building market from a corporate perspective, some limitations persist. At the time of this study, data were only available for the years 2008–2017, and data on green building companies only include 464 representative green contractors and green design firms identified on ENR top lists. Future researchers may collect more data on green building companies (e.g., developers or consultancy agencies) to analyze the development of the green building market. In assessing stages of green development trends based on green revenue generated from representative companies, the factors influencing green revenue are numerous and varied (e.g., company annual budget and change in owners' perceptions). This study mainly discussed factors of LEED version updates and the GFC. More influential factors should be analyzed in future studies. Future work may also incorporate the spatial dimension of green building organizations for a more comprehensive spatial-temporal exploration of the green building market.

Data Availability Statement

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon reasonable request.

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