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# The spatial diffusion of green building technologies: The case of Leadership in Energy and Environmental Design (LEED) in the United States

## ABSTRACT

*The practice of green building aims to reduce negative impacts on the environment and human health and is therefore more sustainable than conventional construction methods. Leadership in Energy and Environmental Design (LEED) is the leading green building standard in the United States and has been adopted by many federal, state and local governments, as well as private developers. This article utilizes data from the U.S. Green Building Council (USGBC), the industry non-profit that governs the LEED standards, to explore the spatial diffusion of LEED projects in the United States.*

## KEYWORDS

green building
diffusion
sustainability
energy
LEED
United States

## INTRODUCTION

Concepts such as 'green' or 'sustainable' are frequently used today in multiple contexts, although often in a vague and imprecise manner. However, these concepts can be highly useful if stringent and commonly accepted

criteria are used to evaluate how green or sustainable something is. One sector of the US economy that is 'going green' is the construction industry. Hence, the practice of 'green building' has emerged, which aims to reduce negative impacts on the environment and human health and should therefore be more sustainable than conventional construction methods that comply with existing codes and regulations, but are otherwise without much regard for broader energy and environmental effects. The green building trend is important because the built environment consumes more than 30 per cent of all energy in the United States (Kibert 2004). In fact, building green is considered one of the most cost-efficient ways of reducing greenhouse gas emissions (Brown and Southworth 2008).

In order to formalize exactly what constitutes a green building, different programmes have been developed. Guidelines for green building in the United States are offered by organizations such as the National Association of Home Builders and the American Institute of Architects. The Federal Government also has multiple green building initiatives, most notably the Environmental Protection Agency's Energy Star programme and the Department of Energy's Building America programme. Internationally, Japan and several countries in Europe also have green building programmes (Deneen and Howard 2007). In the United States, Leadership in Energy and Environmental Design (LEED) is arguably the dominant green building standard and it has been adopted by many federal, state and local governments, as well as private developers.

As green building is rapidly spreading, the objective of this article is to investigate the spatio-temporal diffusion patterns of LEED projects in the United States. Examining the geographic spread pattern sheds light on how green building practices are adopted at different rates in different regions in the Unites States. This, in turn, can suggest how cultural and economic regional differences in the United States have played a role in the emergence of green building. The geographic perspective is important because the sustainable development trends in any society are affected by its spatial structures. To investigate green building patterns, this article primarily utilizes data from the U.S. Green Building Council (USGBC), the non-profit industry that governs the LEED standards. Further comments on the research design are made in the methods section. Before turning to the data analysis, however, it is first necessary to discuss spatial diffusion theory, and, second, to explain the fundamentals of the LEED programme.

## SPATIAL DIFFUSION THEORY

Diffusion is 'the spread of a phenomenon over space and through time' (Gregory 1994). The spread of innovation (e.g. a new practice like green building) has received particular attention and such spatial diffusion research is especially associated with the seminal work of Swedish geographer Torsten Hägerstrand (1967). Diffusion is based on communication between individuals, which facilitates the adoption of a new phenomenon. Spatially, diffusion is also influenced by the 'neighbourhood effect' – when the sociocultural environment in which people operate shapes their actions and attitudes. Therefore, it may be assumed that information diffuses more easily between people and places in proximity to each other and that such flows decrease with distance, a so-called 'distance decay' function. For example, Grattet et al. (1998) noticed a neighbourhood effect in adoption of new US state policies.

Policy innovators are often politically progressive states, such as California, and from there, new policies spread to neighbouring states, followed by other like-minded but non-contiguous states, and eventually to other states. This pattern can be explained, according to Grattet et al. (1998), by the existence of a communication network based on proximity.

However, diffusion may take several different spatial forms. When a phenomenon spreads in a contiguous manner from a point of origin to places further and further away, the process is called expansion diffusion. If the spread is non-contiguous, the term relocation diffusion is frequently used. Hierarchical diffusion usually denotes a spread from larger urban centres to smaller places. Today, information is efficiently carried by mass media, in addition to, and arguably even more than, person-to-person contact, which favours diffusion patterns other than expansion diffusion.

The propensity for individuals to adopt an innovation varies greatly. Most people follow the lead of others and adopt something new at approximately the same time as everybody else. The distribution of adopters over time is therefore often assumed to follow a bell-shaped normal distribution pattern (Morrill et al. 1988). Few people are at the beginning of the curve – denoted 'innovators' and 'early adopters' – and similarly, few individuals are 'laggards', at the end of the curve. Spatial adoption proceeds in a similar manner. Thus, both people and places, depending on where they fall along the normal distribution of adoption, can be called innovators, early adopters, majority adopters or laggards. When centres of innovation emerge, the difference between them and other places is great at first. Over time, adoption spreads and the difference between places and regions tends to diminish.

During the innovation adoption process, individuals have to be convinced that a phenomenon has favourable characteristics, either by direct persuasion as a result of interpersonal communication, which often occurs on the local level, or via information relayed by mass media. The individual most likely to adopt – the innovator – tends to rely on information from mass media, have contact networks that are geographically extensive and exhibit personal traits such as propensity for risk taking, openness to new ideas, technological skills, belief in scientific progress and a general cosmopolitan outlook (Rogers 2003). The next category, the early adopters, are often 'opinion leaders' whom the majority look towards for guidance, and when such individuals adopt and promote an innovation, it diffuses more rapidly to majority adopters and eventually to laggards. Individuals at the beginning of the adoption curve tend to come from higher socio-economic strata, have more education and have control over economic resources (e.g. companies) compared to those towards the end of the curve. At the same time, not adopting an innovation such as LEED could be rational if benefits are unproven. Despite the laudable goal of green buildings, we cannot a priori assume that LEED adoption only has positive consequences and that non-adopters are irrational laggards.

Beyond individual characteristics, the social structures of society where an innovation is introduced influence whether adoption will succeed or fail. For example, LEED is a form of intra-industry diffusion and corresponds to what Brown calls a 'decentralized decision-making structure with a coordinating propagator' (1981: 92). The propagator, or diffusion agency, which is the USGBC in the case of LEED, is an entity through which an innovation is made available to the public. At a certain point, the physical or social infrastructure around the innovation (e.g. LEED-certified architects and

engineers) is sufficient for the innovation to be widely adopted. Moreover, a new technology has to be compatible with existing beliefs and values (Rogers 2003).

Clark (1984) and Brown (1981) argue that diffusion involving large entities (e.g. firms and organizations) fundamentally follows the same pattern as person-to-person diffusion. This perspective has been validated by empirical research showing a pattern of adoption among firms similar to individual adoption (Mahler and Rogers 1999), which means that the diffusion concepts discussed here are applicable in the case of LEED, which is characterized by a combination of individual and institutional decision making.

## BACKGROUND TO LEED

LEED is a certification programme that vouches for a building's green performance. It was developed by the USGBC in the late 1990s and its standards have been widely adopted by the private industry as well as government agencies when new buildings are commissioned.

The first step towards LEED certification is for the developer of a prospective building to register the project with the USGBC. A set of evaluating procedures guide the design of a building so that it qualifies for LEED certification. These guidelines apply to the complete building life cycle – from siting, design, construction, operation, maintenance, to final removal. A project achieves certification by accumulating a minimum number of points in a rating system based on seven categories: energy and atmosphere, materials and resources, water efficiency, sustainable sites, indoor environmental quality, innovation and design process, and regional suitability (USGBC 2011).

Credit-awarding design elements within these categories are too numerous to discuss comprehensively; however, examples include using building materials close to the building site to minimize transportation fuel consumption; the use of high performing windows, doors and insulation; low-impact building materials (e.g. use of recycled, degradable and organic material, or materials with low life cycle impact and low levels of harmful wastes and emissions); and green roofs for reduction of rainwater run-off. Other design elements include the orientation of the structure to take advantage of the angle of the sun, the inclusion of 'greywater' systems (e.g. rainwater collectors or wastewater from dishwashing or washing machines used to flush toilets, water lawns and wash cars) and packed gravel for parking lots instead of concrete or asphalt.

After a building is completed, the developer submits the building specifications to the USGBC, an evaluation is made, the building is (hopefully) awarded LEED certification and it moves from the 'registered' category (i.e. ongoing projects where the developer has declared the intent to build according to LEED specifications) to an actually 'certified' green building. Buildings can qualify for four levels of LEED certification based on the number of points they have accumulated: certified, silver, gold and platinum. One question that has yet to be fully answered is how green LEED buildings truly are. Studies on how LEED buildings perform after they are built are few and far between so far, but show positive, yet mixed results (Deneen and Howard 2007).

Some concerns have been raised about LEED certification. There are costs associated with the registration and certification process. This is especially an obstacle for small projects. The certification process has been described by some as cumbersome, complicated, slow and costly (Schendler

and Udall 2005). Green building also adds to the upfront cost of construction. Some assessments state that the surcharge is only 1 per cent (Deneen and Howard 2007), while others claim that the cost is prohibitively high for many developers (Schendler and Udall 2005). Another critique is that LEED ratings do not always correspond to a project's actual environmental benefits (Stein and Reiss 2004). Developers 'chase' points, not necessarily the best green design for an individual project. For these and other reasons, the share of new construction across the United States that is LEED certified is still relatively small. Especially the residential sector lags behind in building green.

Despite some potential limitations of the programme – the objective of this article is not to assess the pros and cons of LEED – green building is increasingly popular with developers, not only because it lessens the impact on the environment, but because it is believed to make good economic sense in terms of energy savings. The recent take off, which will be documented in detail later, is likely associated with the expectation of higher energy costs in the future. All other things being equal, this suggests that LEED would be more or less uniformly popular across the United States. However, diffusion theory suggests that the adoption of new innovation is a spatially uneven process. Is that true for green building practices in the United States as well?

## DATA

To assess how the practice of green building has diffused, data from the USGBC on all LEED projects were obtained. The data are updated as of January 2009 and thus covers all projects from the inception of LEED in 1998 (the first building was certified in 2000) through 2008. Most projects include information on location, type of project (e.g. office, retail), project ownership (e.g. private, government), certification date, level of certification and so on. The first limitation is that only completed projects are included in the analysis, i.e. those building that have been LEED certified. The overwhelming number of projects are currently in the registration phase, but many of those will never be certified green buildings because, (1) they do not, in the end, pass LEED inspection; (2) the project is never completed; or (3) the builder never intended for the project to be certified but only used LEED registration as a public relations tool during the development process of the building (according to A. Lass at the USGBC 11 January 2009 personal communication). In the diffusion literature, it has in fact been noted that one reason for adoption is the prestige of being associated with an innovative technology at an early stage (Rogers 2003). Second, 2 per cent of projects do not have any location (state) identifier – usually withheld at the request of the developer – and have therefore been omitted from the analysis. Around 30 per cent of the data do not have a city location, which limits a more geographically fine-grained investigation. In the analysis section, emphasis is placed on state and regional level data, although urban data is partially utilized. Third, LEED projects outside United States are omitted. As a US-based programme, non-American LEED projects are not as numerous and barriers to diffusion are different. (Outside the United States, LEED certification was especially popular in pre-recession Dubai.) Within these parameters 2129 LEED-certified projects were identified for the purpose of this research.

## ANALYSIS

In this section, the increase in LEED construction over time is explored, which is subsequently disaggregated geographically by US region. This is followed by comparing the diffusion pattern with different building and ownership categories. Finally, non-USGBC data are utilized to create three regional indices – an urbanization index, a green policy index and a creativity index – that are compared with the patterns of LEED diffusion.

LEED certification has increased dramatically since its inception. The first two buildings were certified in 2000. The first one, The Philip Merrill Environmental Center, is appropriately home to an environmental non-profit organization, the Chesapeake Bay Foundation, in a scenic Annapolis, Maryland location. The second groundbreaking structure is the Firstside Center, which is an office building owned by a financial institution, PNC. Its location is also symbolic; a brownfield redevelopment site near downtown Pittsburgh, PA. From 2000 to 2004, LEED experienced initial rapid growth with a doubling, or more, of certified projects every year. The absolute number of LEED certifications annually, as well as the percentage increase from the previous year is shown in Figure 1. From 2005 to 2008, LEED certifications continued to increase dramatically in absolute numbers, although the growth rate has stabilized around 60–70 per cent annually. The growth pattern suggests that the diffusion of LEED so far has two distinct stages, the innovation stage and the early adoption stage. This is appropriate terminology as green building is still not the norm in the American building industry and maturity will presumably be reached many years from now.

Due to a moderately sized sample, the data have primarily been organized by Census division, which provides an appropriate spatial level of analysis. These nine Census divisions are intended to divide the United States into relatively

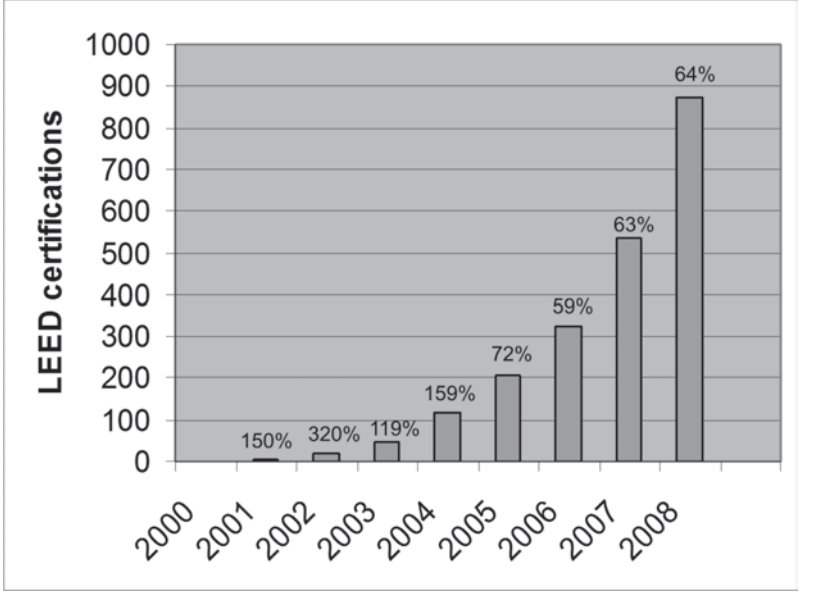


*Figure 1: Annual growth of LEED-certified buildings 2000–2008.*

homogenous regions (U.S. Bureau of the Census 2005). Following the established terminology, regions with an unusually high level of LEED certification during the first stage can be called innovator regions, while regions that exhibit a strong growth pattern in the second stage are early adopters. A third distinction, laggard regions, associated with a low rate of adoption from 2000 to 2008, can also be introduced. In diffusion theory, laggards are generally understood to be places or people who have not adopted a phenomenon long after the majority has done so. Thus, the use of the term 'laggard' when green building is in the early stages of its life cycle and is not truly widespread anywhere, may not be entirely consistent with conventional diffusion terminology, but would nevertheless be useful when studying LEED at this point in time.

The data indicate that both in absolute and relative terms, the Pacific (the states California, Oregon, Washington, Alaska and Hawaii) is the leading innovator region (Figure 2). During the first stage, 64 LEED projects were completed here, which is more than double that of any other region. Even if adjusted for population size[1] the Pacific is still the main region of innovation. A secondary innovation centre is New England. Here, only thirteen projects were LEED certified from 2000 to 2004, but 'projects per million residents' were 0.92, the second highest regional score after the Pacific (1.35).

During the second, or the early adoption stage, the Pacific region maintains its position as a green building leader in the United States. During this stage, the Pacific region still has the highest number of completed LEED projects (453). However, LEED certification has expanded to the nearby Mountain West region, which has almost as many per capita competed projects in the early adoption stage as the Pacific region. The score for the Mountain West region is now 9.09 projects per million residents compared to 9.58 for the Pacific region. This is a significant departure from the innovation stage where per capita LEED construction in the Mountain West region was only half of that in the Pacific region. In the eastern United States, New England solidified its early edge (and even surged ahead of the Pacific region in per capita LEED certification with 10.8 projects per million) but green building diffused

1. To adjust for population size, population estimates by Census division from the U.S. Bureau of the Census for the median year (2004) of the study period was used. As a substitute for population, a test using construction activity by Census division was also performed (using the number of construction workers as reported by the Census' County Business Patterns as a proxy), but no significant differences compared with the population analysis was detected; thus, 'LEED per new construction unit' is not further considered in the article.

*Figure 2: Spatial diffusion of LEED in the United States by region.*

to three nearby regions: the Middle Atlantic, East North Central and South Atlantic (as indicated by the arrows in Figure 2). These three regions exhibited very similar scores both in the innovator stage (approximately 0.5 projects per million) and the early adoption stage (approximately five to six projects per million), which consistently means half the amount of New England LEED construction. East North Central had a slightly better growth trajectory than the other two regions, but in absolute numbers, the South Atlantic region completed more LEED buildings (310) during the early adoption stage than any other region after the Pacific region. Due to overall fewer LEED projects than the Pacific and New England, although some catching up with the innovator regions was evident, the four regions Mountain West, Middle Atlantic, East North Central and South Atlantic may be placed in the early adopter category.

Parts of the South (East South Central and West South Central) and the Great Plains (West North Central) exhibit distinct laggard tendencies, both in the innovation stage (where these regions only had four to nine LEED-certified buildings each), and the early adoption stage (where they continue to lag significantly behind all other US regions both in absolute and relative terms). East South Central (comprised of Alabama, Kentucky, Mississippi and Tennessee) is consistently at the bottom with five to six times fewer green buildings than leading US regions.

The USGBC data also show the functional categories that LEED-certified buildings belong to, such as office, residential, industrial, educational and so on. Overall, LEED has been most successful among developers of office buildings. In this category, 562 projects were completed from 2000 to 2008, which should be compared to 107 in the second highest category, higher education and less than 100 in other individual categories. (Note that 637 projects are classified as 'multi-use' structures and their primary use is hard to decipher without detailed analysis on the individual building level.) Some of the regional differences in the diffusion pattern can be attributed to the different types of LEED buildings that have been constructed in different regions. Although LEED office development is also most widely diffused geographically, laggard regions tend to have a greater share of office buildings among its mix of green buildings. For example, approximately 40 per cent of the LEED projects in West North Central and West South Central regions are office buildings. On the other hand, the New England innovation region only has 19 per cent office buildings. Overall, New England has a unique pattern where green university buildings are unusually numerous, representing 10 per cent of the region's LEED projects. The region is also known for many prominent institutions of higher education. Moreover, green residential and retail buildings make up a greater share in New England than in any other region. Elsewhere, certain individual building categories are occasionally over-represented. The Middle Atlantic region has a cluster of financial LEED buildings, which is entirely due to the green building practices of one corporation, Pittsburgh-based PNC Bank. While the original decision by PNC to invest in green building was largely coincidental, the practice has developed into a broader corporate branding strategy that not only includes the aforementioned showcase headquarters building, but also LEED-certified bank branches throughout its market area in Pennsylvania and bordering states (Stewart 2008). In the East North Central region, green health care buildings are widespread but not associated with a particular location or owner.

Ultimately, it is those who finance a project that decide whether a new building should be designed according to LEED specifications. The USGBC database

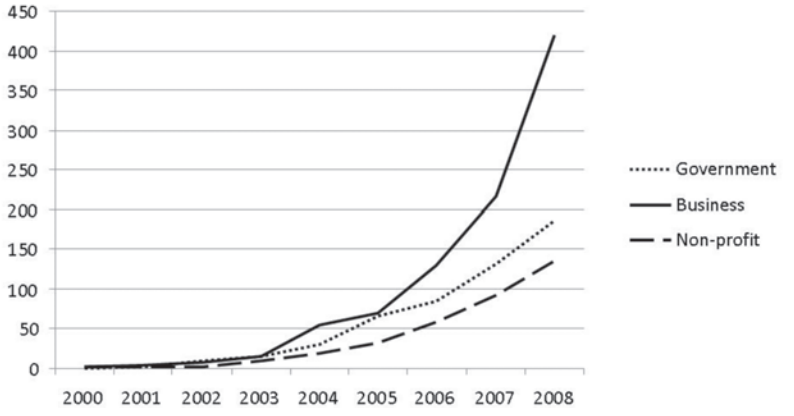


*Figure 3: The temporal development of LEED buildings by ownership category.*

contains information on the ownership patterns of green buildings. During the innovation stage, the public and the private sector invested an equal amount in green buildings (Figure 3). As most construction in the United States is privately financed, it is fair to say that the government played an important role initially; it took on a role as a demand generator by adopting LEED. Over time, however, the business sector has exponentially invested in green buildings, far outpacing the public sector. By 2008, private builders developed more than twice as many LEED projects as government entities did. The non-profit sector exhibits a growth trend similar to the public sector and therefore also lacks a dynamic growth pattern towards the end of the study period.

Furthermore, there is a distinct temporal pattern in the propensity for different spatial scales of government to build green (Figure 4). The Federal Government exhibits the weakest growth over time, followed by state governments, while local governments have been more eager over time to invest in green buildings. Thus, within the public sector, local governments

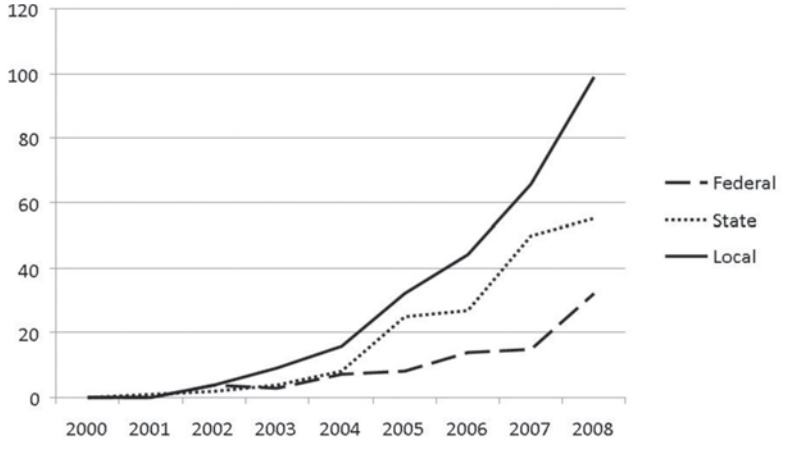


*Figure 4: The temporal development of LEED buildings by government category.*

more closely resemble the business sector pattern with a dramatic increase in the second LEED diffusion stage.

While the Federal Government did not, as noted, emerge as a leader in green building, it has had a disproportionately high impact on green building in the Mountain West and in the South Atlantic regions, where approximately 8–9 per cent of LEED projects are federal buildings. In the Mountain West region, local governments also build more LEED-certified structures than anywhere else – almost 22 per cent of all LEED projects. State governments, on the other hand, have been more active ordering green buildings in the Pacific region – 12 per cent of all LEED projects. In laggard regions, the trend is distinct: a majority of green buildings originate in the business sector in West South Central, West North Central and East South Central regions, while the public sector plays a smaller role. In the other regions, only the Middle Atlantic has a majority of LEED projects built in the business sector. Green building in the non-profit sector, on the other hand, varies geographically, but is on par with the business sector only in New England where 31 per cent of green buildings were built by non-profit organizations. New England is a region with well established non-profit organizations, many dating back to the time in the region's history when it was an economic centre of the country.

Over time, green builders have become more ambitious. Gold- and silver-certified buildings are increasingly common, with silver being the dominant designation since 2006. The lowest level – 'certified' – was the most common category during the innovation stage and until 2005. While the number of certified-only structures grows annually, it has fallen behind silver and gold buildings. During 2008, 305 silver projects were completed, 275 received the gold designation and 201 were classified as certified-only. The premium platinum designation also grows fast, much like silver and gold, but on a much smaller scale; only 43 were completed in 2008. By region, it is the innovative Pacific region, and also the early adopter region of the Mountain West, where construction tends to be skewed towards the greenest of green buildings, and so where 41–43 per cent of all LEED projects were designated platinum and gold. The laggard East South Central region exhibits the opposite pattern – a bias towards building less ambitious green buildings. As many as 83 per cent of the LEED projects in the East South Central region are only designated certified or silver.

Additional non-USGBC data can contextualize the patterns that have been explored so far. As stated in the literature review, a phenomenon observed in many diffusion studies is hierarchical diffusion – a spread pattern from larger to smaller places. The two columns to the left in Table 1 show that the leading innovator region, i.e. the Pacific region, is also the most urban (91 per cent) in United States, using data from the 2000 Census. The three laggard regions are conversely the least urbanized, ranging from 57 to 77 per cent. The middle category, early adopters, tends to fall somewhere in between in the rate of urbanization.

However, further analysis shows only mixed support for a hierarchical diffusion pattern. Moving beyond the macro regions as the spatial unit of investigation, the LEED data was reorganized into five categories[2] based on the size of the cities where LEED construction is taking place, from large metropolitan areas with more than 5.3 million people to small non-metropolitan areas (Table 2). Non-metropolitan areas stand out as having by far the fewest green buildings per capita. Beyond non-metropolitan areas, however, the propensity to build green does not increase with city size. It is in the mid-sized

2. The categorization started with non-metropolitan areas as a given category, which totaled approximately 55 million people. The objective was then to design categories that have, as closely as possible, the same number of people totally. This generated four additional larger size categories that ranged from 53 to 57 million people. All population data are from the 2000 US Census.

| | Urban (%) | Index | Green score | Index | Creativity score | Index |
|---|---|---|---|---|---|---|
| East North Central | 77.7 | 101 | 26.7 | 87 | 104.6 | 84 |
| East South Central | 57.1 | 74 | 19.4 | 63 | 56.9 | 46 |
| Middle Atlantic | 85.7 | 111 | 35.2 | 115 | 157.5 | 127 |
| Mountain West | 82.5 | 107 | 35.3 | 115 | 124.5 | 100 |
| New England | 80.6 | 104 | 37.5 | 122 | 159.3 | 129 |
| Pacific | 91.1 | 118 | 38.3 | 125 | 172.8 | 139 |
| South Atlantic | 75.7 | 98 | 30.8 | 100 | 121.2 | 98 |
| West North Central | 67.7 | 88 | 28.2 | 92 | 88.5 | 71 |
| West South Central | 76.7 | 99 | 24.5 | 80 | 130.1 | 105 |

*Table 1: Regional characteristics: urbanization, environmental policy (green score) and level of creativity (creativity score).*

city category with 2.4 million to 750,000 residents each where most LEED projects are found. The number of green buildings then decreases slightly in the two large city categories. Temporally, no strong diffusion trend based on city size is detected. Typically, 10 per cent of LEED projects were built during the innovation stage (2000–2004) and 90 per cent during the early adoption stage (2005– 2008). The small temporal differences that do exist again indicate that it is the mid-sized city category that appears to be on the cutting-edge, with 11.7 per cent of its LEED projects completed during the innovation stage. The largest (>5.3 million) and the smallest (75,000–750,000) metropolitan areas only completed around 8 per cent of their LEED projects in the innovation phase. Thus, the 'classic' larger-to-smaller cities diffusion does not have a clear-cut pattern, even if far fewer green buildings are constructed in small, non-metropolitan areas.

An additional way to assess LEED diffusion on the urban level is to focus on individual cities. There are clear differences between cities, even those of the same size (with the caveat that 30 per cent of LEED projects do not have a city location in the USGBC data, which makes the conclusions here somewhat tentative). More than a third of all the LEED-certified buildings have been built in ten metropolitan areas (Table 3). Many of them are in the big

| City category | Aggregate population (in million) | Total LEED projects | LEED projects 2000–2004 | Perce-ntage of total | LEED projects 2005–2008 | Perce-ntage of total |
|---|---|---|---|---|---|---|
| Non-metropolitan | 54.7 | 108 | 12 | 11.1 | 96 | 88.9 |
| 75,000–750,000 | 57.9 | 381 | 32 | 8.4 | 349 | 91.6 |
| 750,000–2.4 million | 57.6 | 515 | 60 | 11.7 | 455 | 88.3 |
| 2.4–5.3 million | 57.3 | 468 | 53 | 11.3 | 415 | 88.7 |
| >5.3 million | 53.1 | 321 | 25 | 7.8 | 296 | 92.2 |

*Table 2: LEED projects by city category and diffusion stage.*

US cities, but some are not. The highest number of LEED buildings (86) is found in the nation's second largest city, Los Angeles, and in much smaller Portland, OR. In Michigan, moreover, 54 LEED certifications have been issued in Grand Rapids, compared to eighteen in much larger Detroit, a city nowhere near the 'top list'. The metropolitan area of Grand Rapids has a population of approximately one million people, which makes it the city in the United States with the highest green building density (see right column in Table 3). In Grand Rapids, a local philanthropist is credited with funding and popularizing local green building (Leonard 2006). Temporally, the best examples of urban innovators are in the Pacific region. The cities of Seattle, Portland and San Francisco developed a greater share of their LEED buildings during the first stage than other leading cities. This is especially pronounced in Seattle where 21 per cent of the city's LEED buildings were completed during the 2000–2004 stage. In Portland, one of the other innovator cities, Allen and Potiowsky (2008) state that several supporting factors are in place, including a critical mass of cutting-edge firms, skilled workers, supportive institutions, high demand and a well-developed supply chain. Encouraged by such fundamentals, local capacities to build green have developed. In many other markets, these factors are not present and the lack of skills and knowledge hampers the development of green building (Krieger 2008). More than 40,000 professionals, particularly architects and engineers, are LEED accredited, but they tend to be concentrated in large cities (and not necessarily in the same places where green building is occurring) (Cidell 2009). Nevertheless, all cities in Table 3 are located in innovative or early adopter regions, except Austin which is the research, hi-tech and university hub of Texas.

The three largest cities in the United States – New York, Los Angeles and Chicago – show a different pattern; few green buildings during the early years of LEED, but a dramatic increase more recently. In New York, for example, only 4 per cent were constructed during the innovation stage. There are also notable laggards among US cities; south Florida (Miami-Fort Lauderdale-West Palm Beach), Memphis and New Orleans stand out among sizeable cities as having almost no LEED-certified buildings. Overall, cities in Florida,

| **Total LEED projects** | **LEED projects per 100,000 residents** |
|---|---|
| 1. Los Angeles, CA (86) | 1. Grand Rapids, MI (4.96) |
| 2. Portland, OR (86) | 2. Portland, OR (3.80) |
| 3. Seattle, WA (77) | 3. Seattle, WA (2.32) |
| 4. Chicago, IL (76) | 4. Denver, CO (1.86) |
| 5. Washington, DC (71) | 5. Pittsburgh, PA (1.82) |
| 6. Boston, MA (66) | 6. Austin, TX (1.60) |
| 7. New York, NY (61) | 7. Raleigh-Durham, NC (1.60) |
| 8. San Francisco, CA (58) | 8. Washington, DC (1.39) |
| 9. Grand Rapids, MI (54) | 9. Boston, MA (1.30) |
| 10. Atlanta, GA (52) | 10. Atlanta, GA (1.26) |

Note: Only cities in the three largest size categories, metropolitan areas with more than 750,000 residents, are listed.

*Table 3: Top LEED cities.*

parts of the mid-South (e.g. Memphis, Tulsa, Oklahoma City) and some 'rust belt' cities (e.g. Hartford, Cleveland, Providence) score poorly. Thus, adoption of LEED is uneven within regions as some of these laggards are found in innovator (New England) and early adopter regions (South Atlantic).

In the literature review section, two additional factors were hypothesized as influencing the diffusion of LEED in the United States. First, places and regions differ in their attitudes towards environmental protection. The business-oriented magazine *Forbes* recently ranked all US states on the basis how green they are (Wingfield and Marcus 2007), including both a healthy environment and environmentally progressive policies as indicators. In the two middle columns of Table 1, a green regional score has been developed based on the *Forbes* ranking of US states and an accompanying index where 100 indicates the mean. It is reasonable to assume that the adoption of green building and general green policies may exhibit similar spatial patterns. The greenest regions are, according to Figure 1, the Pacific region and New England, which also are the two innovative regions in the LEED data. The green score by region exhibits a near perfect correlation with the LEED adoption curve with the East South Central region having the lowest score.

A second factor is the general propensity to develop and adopt innovations and how that varies among places. Some places have been shown to be more consistently 'creative' than others. The best known assessment of the geography of creativity comes from Richard Florida and his notion of the 'creative class' (Florida 2002). Places such as San Francisco, Austin, Boston and Seattle have a large share of workers with high educational attainment in fields that are classified as innovative, and more patents originate in such places. Architects and engineers are the main 'knowers' of building green and also parts of Florida's creative class designation; so an association between innovative places and adopters of LEED appears logical. The hypothesis is that LEED is adopted early in creative places and diffuses to other places over time. Most of the 'top 10' creative cities (e.g. San Francisco, Boston, Seattle and Raleigh-Durham) are also found in Table 3 and conversely, many of the least creative cities, according to Florida, have, if at all, completed very few LEED projects (e.g. Memphis, Oklahoma City, New Orleans, Providence). Grand Rapids, as one of the least creative cities but with many LEED buildings, is the exception. Florida's best known creativity index compares cities, but an index on the state level is also available (Catalytix, Inc and the Richard Florida Creativity Group 2003). The two columns to the right in Table 1 show the creativity scores organized by Census division and an indexed score with 100 as the mean. The creativity index correlates well with LEED. The innovative regions New England and Pacific have the highest creativity score and, conversely, the laggard regions of East South Central and West North Central have the lowest creativity score. One exception is West South Central, which is a laggard region in LEED construction, but has an above average creativity index.

## CONCLUSION

The green building practice has expanded rapidly in the United States in two stages: an innovation stage, from 2000 to 2004; and an early adopter stage, from 2005 to 2008. This article has shown how geographic differences in the adoption of green building exist, which is expected with a relatively new practice. The Pacific coast region is the epicentre of green building in

the United States where many LEED projects emerged during the early years, and New England, a secondary centre. An expansion diffusion pattern from coast to inland is evident on a regional scale. While this could be attributed to a border effect when local knowledge in innovation regions spills over to nearby areas via person-to-person contacts, such an expansion diffusion pattern may also be a function of spatial continuity of socio-economic characteristics and attitudes. Such cultural and economic conditions are generally similar among places in close proximity. For example, creative economies of US regions appear to be associated to a very high degree with green building and 'green ideology'. The new technology and norms in the building industry that LEED represents have developed in part as a result of social factors; the increasingly accepted notions of energy efficiency and environmentalism. Thus, green building is an outcome of broader green attitudes in society; however, it is filtered through the creative tendencies in regional economies.

As indicated in the section on diffusion theory, diffusion may also be hierarchical in nature – innovative policies commonly spread from urban to rural areas. While such a hierarchical diffusion pattern is evident at the macro-regional level, it is less so at the city level. Mid-sized cities adopted LEED early and most thoroughly, while the largest cities lag behind somewhat, and small non-metropolitan have the fewest per capita LEED projects. This conclusion appears to support the idea that local clusters of knowledge are highly important. Recent research on Portland, OR has confirmed the importance of local clusters and mid-sized cities can therefore be centres of innovation. On the micro-scale, where information is often transferred from person-to-person, an element of chance is present in the spread pattern – for example, the high level of green building in Grand Rapids, which is a city outside the innovative core of the United States. However, such 'anomalies' disappear on the macro-scale. The large spatial scale emphasis in this study 'smooth out' the irregularities and partial random effects associated with individual-based diffusion.

Over time, the private industry has come to dominate green building in the United States, and especially office building category. In regions that are on the forefront of adopting LEED, however, the government played a greater role in supporting green building during the innovation stage. These innovative regions are also more prone to invest in advanced gold and platinum LEED buildings. Conversely, laggard regions exhibit more modest government involvement; instead, private sector office construction dominates. While government played a role in the innovation stage, the profit motive is taking over as a leading force, and the private sector now dominates green building in all regions. This is typical of innovative, yet untested, technologies. Early government support functions (1) as a demonstration model for what works, and (2) to generate initial demand in the industry. The role of government is still important today by encouraging the adoption of LEED. Numerous local and state policies encourage, and even require, developers to adopt green practices through tax incentives and regulation (Deneen and Howard 2007; Webb 2007; Parris 2007). Future research should focus on how state and local polices influence the spatial pattern of LEED adoption. Other geographical variables that need to be investigated further include local environmental circumstances; in fact, one of the critiques of LEED is that its point system (until recently) does not sufficiently take into account such geographical differences (Brook 2008). Cidell and Beata (2009) have noted that developers do modify the character of their LEED projects based on local and regional differences, which is a good first step to further explore the spatial dimension of green building.

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