Energy & Health:

Green Building Rating System

Course: Information Visualization and Presentation (2020 Spring), Professor Marti Hearst

Name: Jing Yuan, MS, BE, Center of Built Environment, Department of Architecture

Email: jingyuan10@berkeley.edu

Table of Contents

1. Project Goal

Green building, or sustainable design, is the practice of increasing the efficiency with which buildings and their sites use energy, water, and materials, and of reducing impacts on human health and the environment for the entire lifecycle of a building. Green-building concepts extend beyond the walls of buildings and include site planning, community and land-use planning issues as well. The growth and development of our communities has a large impact on our natural environment. The manufacturing, design, construction and operation of the buildings in which we live and work are responsible for the consumption of many of our natural resources. Green building rating systems can help designer reform their design and increase the performance of both buildings and residents.

In recent years, people not only care about the energy consumption of the building itself, but also pay attention to the health performance of the residences. Because both of our mental and physical health conditions are highly related to the indoor environments that we spend 90% of our time in, residents are eager to live in a healthier space. Therefore, it is of vital importance to study whether developers adopted green building design factors into their projects, whether developers are interested in incorporating health-related strategies in addition to the energy-only system, and the feasibility of applying health-related design factors in different scales of building projects.

This interface focuses on the exploring and explaining the history of both green building rating systems, and designing a knowledge corner for developers and designers to have an overview of both the Energy and Health oriented Rating systems and aid their decision making. To achieve this objective, two rating systems are selected to represent the energy-oriented and health-oriented rating systems respectively: LEED (Leadership in Energy and Environmental Design) and WELL (The WELL Building Standard). In order to explicitly explain this topic, this project aims to do four things:

- Goal1: Emphasize the positive effect of applying sustainable design strategies on both building and urban scale;

- Goal2: Understand what criteria are included in LEED and WELL rating system, what is the evaluation process and what design strategies should be done primarily for each rating system;

- Goal 3: Show the general knowledge of buildings that adopted LEED or WELL rating system across the world;

- Goal 4: Compare the feasibility of LEED and WELL system through different aspects.

In order to provide a deep understanding of these two rating systems with an engaging interpretation, in this part I will focus on the cases in the U.S. for which there is an extensive dataset on green buildings. And till the end of this interface, the viewer or developer will have a comprehensive understanding of green building development, matching their needs to one or both of the rating systems based the features of their projects and aiding the decision-making process in the early design phase.

2. Related work

The aim of this project is to compare two green building rating systems that were developed in the United States. Plenty of studies had made comparison between different building systems, but most of the studies only focus on the rating system itself without looking at the project details. In my project, I want not only to compare the criteria or the popularity of rating system, but also how these rating systems works in real project. However, it is worthy to study how literatures do these comparisons at the beginning point.

2.1 Studies about the geographical distribution of the rating system

First of all, some studies compare the number of the rating system existed in each country. For instance, one of the studies used the world map with different intensity of color to show the total number of rating systems. From this map, viewer can get an overview of which country is more advanced in building rating system establishment. But, in my opinion, this visualization failed to convey information sufficiently, since the number of rating system is not related to the size of the country but may related to the development of the country. It might be better to use bar chart instead of use map.

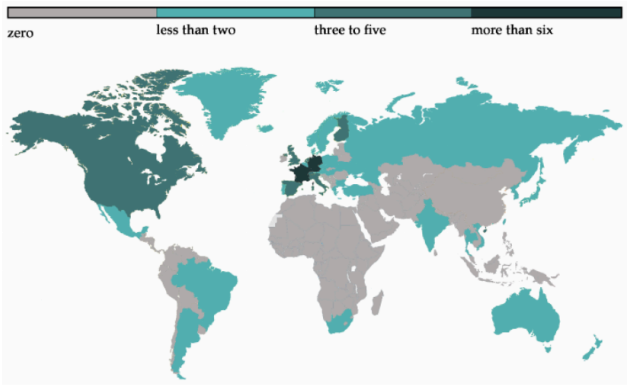


Figure 3. Number of rating systems for assessing the environmental impact of buildings available per country.

(Source: Bernardi, Elena, Salvatore Carlucci, Cristina Cornaro, and Rolf Bohne. "An Analysis of the Most Adopted Rating Systems for Assessing the Environmental Impact of Buildings." Sustainability 9, no. 7 (2017): 1226.)

2.2 Studies about the prevalence of rating system

And in order to show the prevalence of the building rating system, some studies focused on studying the number of articles that mentioned green building rating system or certain rating system in each year. For example, in Doan's study, they used bar chart to show the time trend of the total number of related papers. And along with a parallel bar chart, they also used a pie chart to show the percentile relationship between related papers published in each selected journal. But, when they draw this pie chart, it does not make sense to simply use the total number of papers in each journal with considering the total number of the articles in each journal.

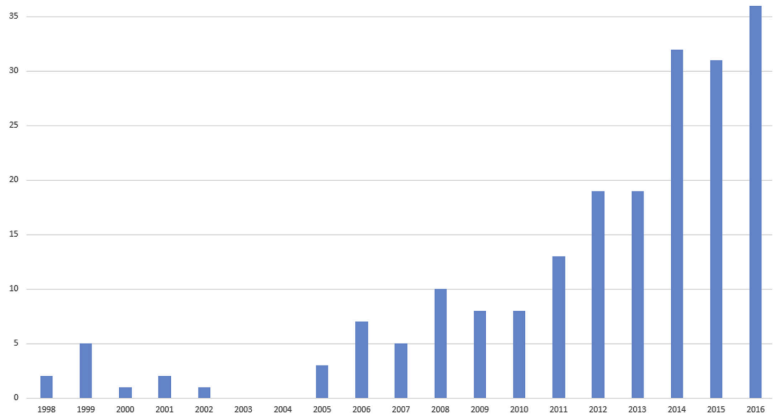


Fig. 9. BREEAM, LEED, CASBEE, and Green Star NZ related papers published from 1998 to 2016.

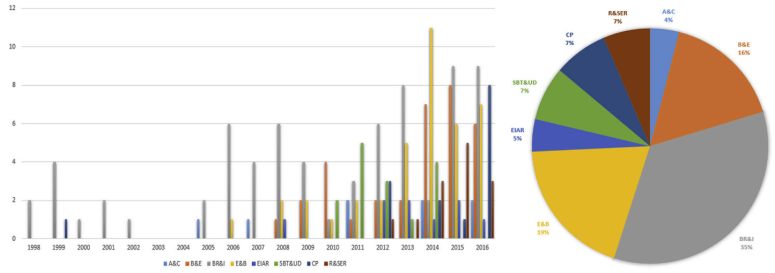
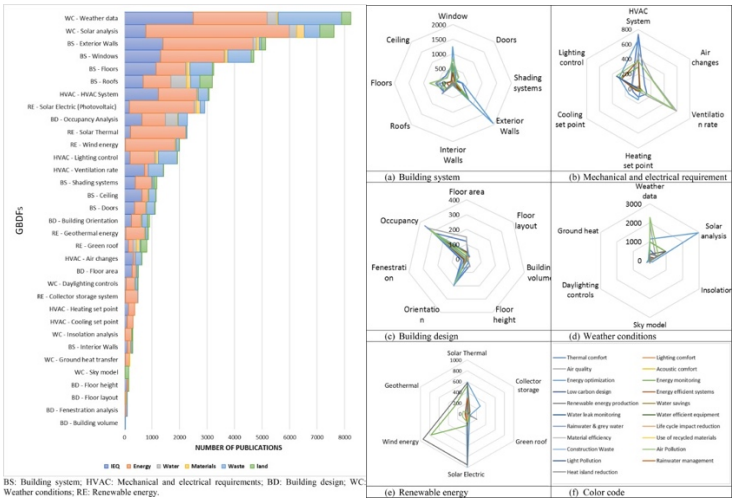


Fig. 10. BREEAM, LEED, CASBEE, and Green Star NZ related papers published in each selected journal.

(Source: Doan, Dat Tien, Ghaffarianhoseini, Ali, Naismith, Nicola, Zhang, Tongrui, Ghaffarianhoseini, Amirhosein, and Tookey, John. "A Critical Comparison of Green Building Rating Systems." Building and Environment 123 (2017): 243-60.)

2.3 Studies about the criteria

Also, a large number of comparisons were made for building design factors or the criteria between different ranking system, but they did not do it in a proper and understandable way. For example, in Alwisy's study, they tried to compare the factors that were adopted in each criterion, by using the number of papers studying building rating systems. From the bar chart, it is easy to see that a large number of papers focusing on whether data, but the comparison of factors within a specific criterion of building systems is pretty hard. Radar chart is a great tool comparing multiple variables, thus they created 5 radar charts that represent different categories of building systems and tried to show the relationship between properties of the criteria with building design factors. From the table showing below the chart, we could find that each property only belongs to a single criterion, but the author decided to put all the legend together with similar colors, which made it harder to understand this radar chart and cause misunderstanding.



Criteria-based GBDFs ranking (left). Categorized ranking comparison (right).

IEQ	Energy	Water	Material	Waste	Land
Thermal comfort	Energy optimization	Water savings	Life cycle impact reduction	Construction Waste	Rainwater management
Lighting comfort	Energy monitoring	Water leak monitoring	Material efficiency	Air Pollution	Heat island reduction
Air quality	Low carbon design	Water efficient equipment	Use of recycled materials	Light Pollution	
Acoustic comfort	Energy efficient systems	Rainwater & grey water			
	Renewable energy production				

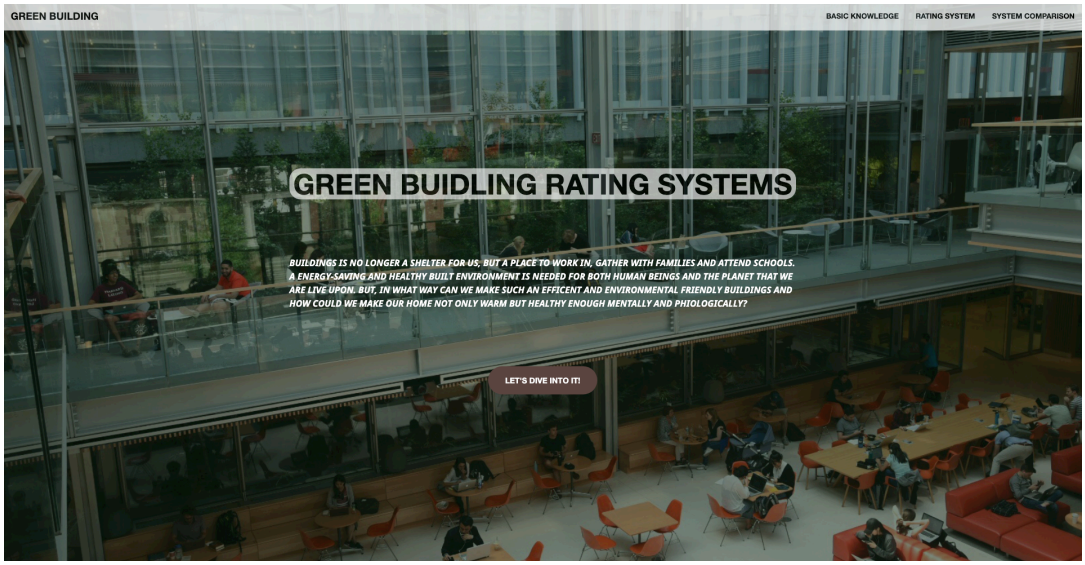
Criteria and its properties

(Source: Alwisy, Aladdin, Samer BuHamdan, and Mustafa Gül. "Criteria-based Ranking of Green Building Design Factors According to Leading Rating Systems." Energy and Buildings 178 (2018): 347.)

Those precedent studies enlightened me with the way of making comparison, but I will create visualization in an interpretable way. Moreover, instead of only studying the structure of rating system itself, the information of certified projects will also be included as well to compare two selected green building rating system in this project.

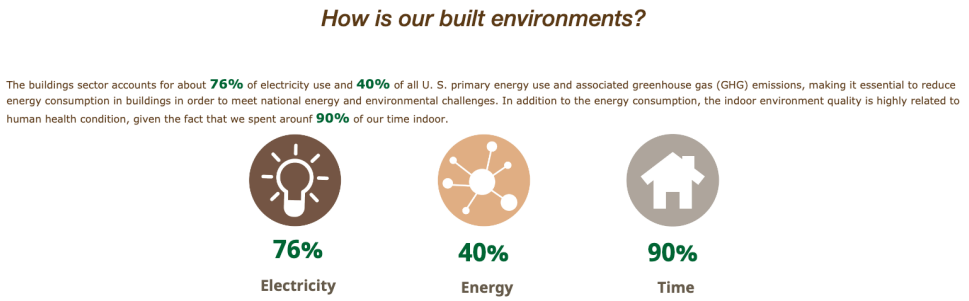
3. Description of the Visualization

In my final website, I build up a knowledge tree of green building rating system from basic introduction of green building, the development of rating systems, to the comparison between two iconic rating systems by using interactive and narrative graphs. Designers or developer may be informed with the following three points: 1) Green building rating system will improve the performance of their building systems; 2) Not only energy but also health aspects should be considered in their design process; 3) LEED and WELL are well-developed with different ways of application.

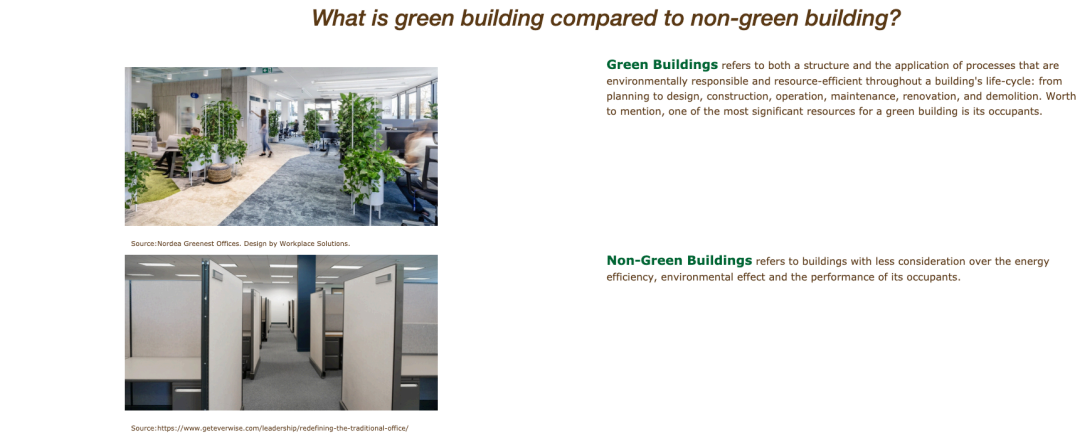


3.1 Introduction to green building and green building rating system

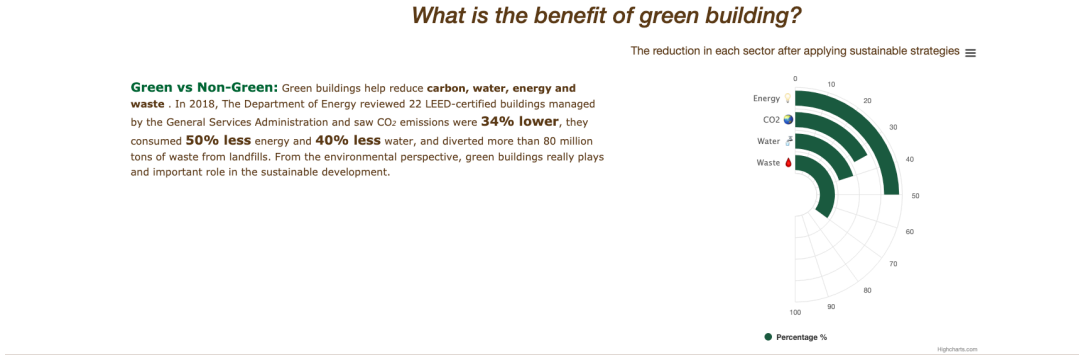
1) At the very top of the website, I highlight the importance of the built environment to energy and human well-being. I used three icon with numbers to show the exact percentage of electricity and energy used by the building as well as the percentage of time people spent indoor. In this way, viewers will get the message that building consume money, energy and time, we need to do something to reduce these costs.



2) Then, I offer the possible solution to the problems that I point out in the former part by casting a comparison between green and non-green buildings. I use pictures of two office to show the difference between green and non-green design strategies. Key features of both buildings are summarized on the right of the corresponding picture. Compared to the non-green office, the green office replace part of the artificial light with natural daylight and open space strategies are adopted instead of use work cube.



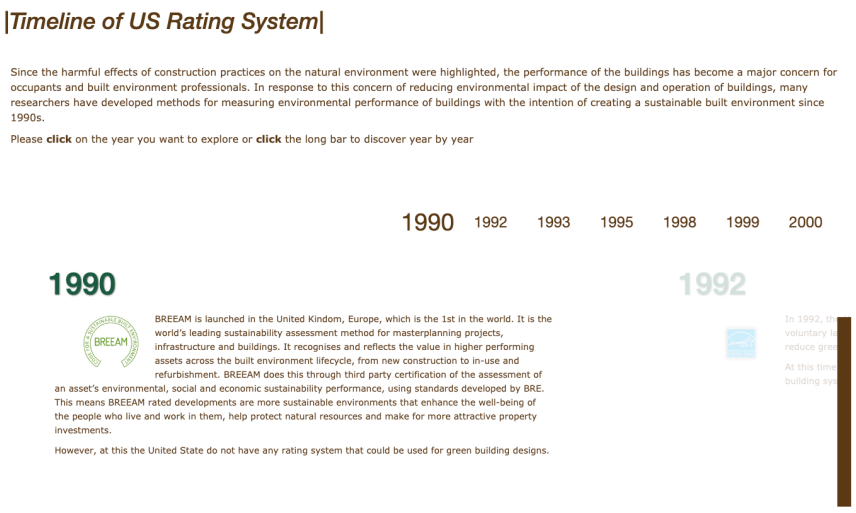
3) After the statement of the features, I used a bar chart in a half-circle shape to show how much resource could be saved if green building strategies are incorporated into design. I selected four predominant aspects to highlight the effectiveness of these strategies: Energy, CO2, Water and Waste. After viewing the graph, viewer should have an impression that green building strategy could help with solving the problems.



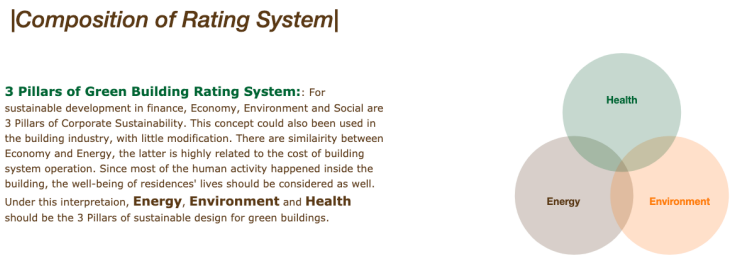
4) Finally, I introduce the green building rating systems to the viewers by using a combo of logos of rating systems along with a brief introduction of the system function. Till now viewer should know why they need to do green building and who can help them with achieving this goal.

3.2 the development of green building rating system

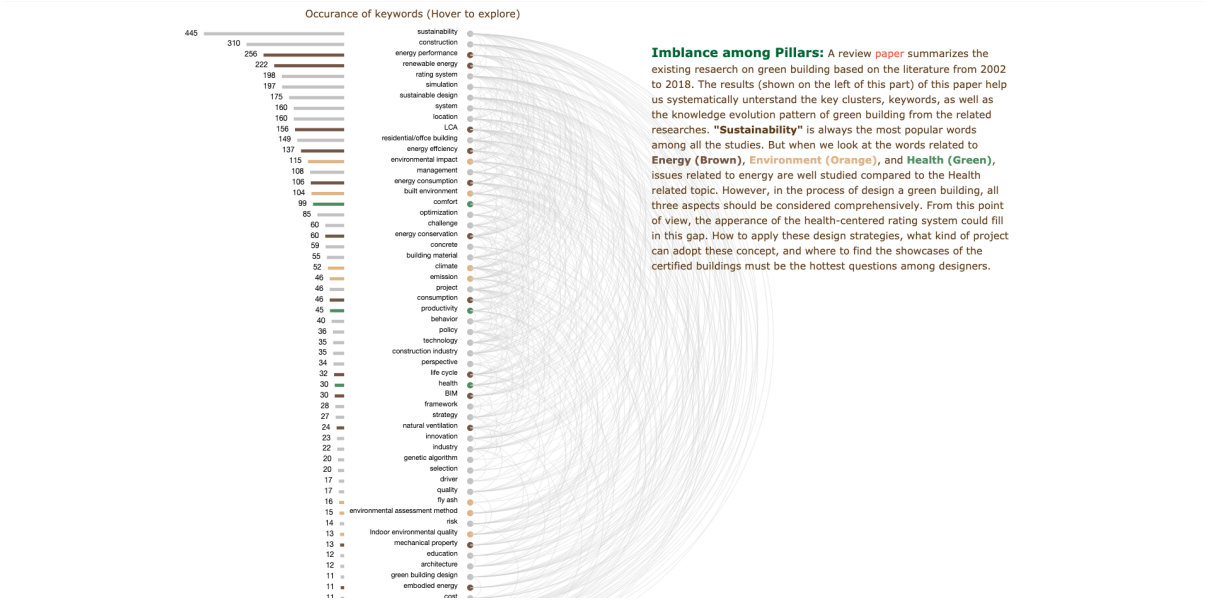
1) Given the fact that the target audience of this visualization are designers and developers who are easy to stick to traditions, it is of vital importance to let them jump out of the comfort zone and know the up-to-date rating systems. I designed an interactive timeline here. Viewers can explore the development of rating system in the United State chronologically. Or they can simply jump into the year they are interested in. After the interaction and reading the corresponding words, they should know that the focus of the rating system is changing.



2) Then, I point out 3 pillars of green building rating systems: Energy, Environment and Health by using a venn graph. I made three circles with same radius, because, the 3 pillars should be equally important for every rating system. Use an iconological graph like this will leave an deep impression on viewers that they need to consider all three aspects in their design and decision -making process.



3) Finally, I extract data from a paper talked about the key clusters, key words, as well as the knowledge evolution pattern of green building from the related researches. I used an arc-graph along with a bar graph to rank the popularity of the key words and the relationship between each key word. Viewers can hover over the key words based on their interests, meanwhile they will find the related words and the frequency of this key word. Moreover, I also color key words related to energy, environment and heal into different color in order to show that even with in the academia, little researches talked about the health aspect of the rating system. After viewing this part, viewers should understand the 3 pillars more deeply and know the weak points of most of the rating systems.



3.3 The comparison between two rating systems

1) This is the major part of this visualization. At the beginning of the visualization, I reintroduce the LEED and WELL green building rating system. By doing this, viewers should know that the following comparison is focused on these two rating systems, and they could also review the focuses of each rating system again before comparison.

LEED (Leadership in Energy and Environmental Design) is an internationally recognized green building certification system, providing third-party verification that a building or community was designed and built using strategies aimed at improving performance across all the metrics that matter most.

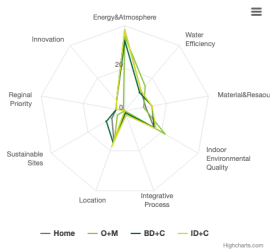
WELL (The WELL Building Standard) is a performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and wellbeing.

Although, both of the building rating system are aiming to improve the built environment in a sustainable way, they are different in their main consideration of the criteria. To be specific, LEED tends to evaluate the project from the standpoint of building performance, such as energy consumption and environment quality. However, for WELL, it credits the project from residents' perspective, for instance, WELL cares about residents' thermal and visual comfort, mood and behavior. When it comes to the consideration of human factors, it is harder to achieve compared to the building focused rating system. But the truth is that both of our mental and physical health conditions are highly related to the indoor environments that we spend 90% of our time in, residents are eager to live in a healthier space. Therefore, it is of vital importance to study whether developers adopted green building design factors into their projects, whether developers are interested in incorporating health-related strategies in addition to the energy-only system, and the feasibility of applying health-related design factors in different scales of building projects.

2) Side-by-Side Comparison: In this part, I compare these two systems by using parallel graphs to show features of each system, because it is hard to compare systems with different criteria in a same graph or show the top 10 regions of two system using one bar graph.

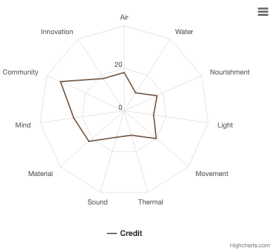
i) First of all, I compare the criteria of each systems by using spider graphs. Viewers can easily find out that LEED put more credits on energy-related criterion, however the top 2 criteria in WELL are community and mind of human. And viewers can also explore LEED criteria for different type of projects. To further emphasis this idea and help viewer have a better understanding of the spider graphs, I give a one sentence summery, " LEED focuses on Energy; WELL focuses on human and Wellbeing".

|Side-by-Side Comparison|



Note: refer to different project types
O+M: Operations and Maintenance;BD+C:Building Design+COnstruction;
ID+C:Interior Design and Construction

LEED



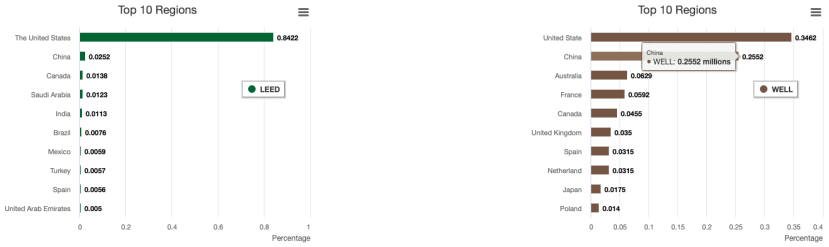
Note: refer to the total credit need for a criterion

WELL

Criteria: LEED focuses on Energy; WELL focuses on Humen and Wellbeing.

In the rating process of LEED, there are 7 criteria, including energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts. For WELL, the evaluation based on air, water, nourishment, light, fitness, comfort, and mind. For both of the green building rating systems, the more points awarded the higher the level of certification achieved from Certified, Silver, Gold, to Platinum. From the spyder graphs, we could see that a large proportion of the credits are given to Energy & Atmosphere in LEED. For WELL, the criterias were create most from the activity of human, and large amount of credits come from Community and Mind.

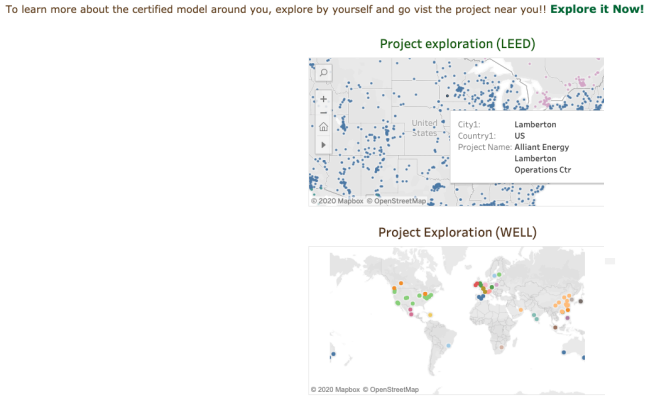
ii) Then, I used two bar graphs to show the Top 10 regions of the projects for each rating systems. Because, both the systems were born in the United States, the distribution of the project could reflect that both systems could also be used by projects outside of the US and WELL is more acceptable worldwide compared to LEED. The underneath reason might be that WELL is the first green building rating system in the world that considering health. From these graphs, designers may opt to WELL standards if they have a project outside of the US.



Regions: Most of LEED projects in USA; WELL's projects are worldwide.

Green buildings are no longer rare, they already exist around us. Although LEED and WELL are created in the United States, they were used worldwide. For LEED, more than 80% of the projects came from America. Compared to the LEED, only 35% of the projects are in the US and 25% of the project came from China, and 6% of them from Australia. The globalization of WELL thanks to its innovation on the human-orientied crateria which is the first to do so.

Iii) LEED is more than 20 years old and WELL is 6 years old, So, designers or developer can learn from successful projects nearby. Thus, after the comparison of the region, I also plot the location of each project on a map. Viewers can not only see the distribution of the project, but also can find out the project right next to their neighborhood or in their countries by zoom in the map. The Location and the name of the project will show as they hover above the project 'dots'.

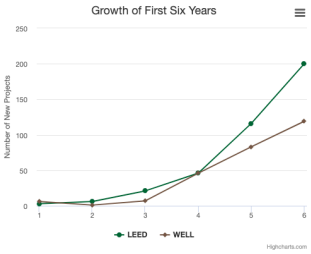


2) All-Together Comparison: In this part, I merge data from LEED project inventory with the WELL project Inventory. Viewers will see four comparisons: project growth rate, types of buildings, certified levels and sizes of the project.

i) First of all, I compare the project growth of the first-six years. Although, LEED is more than 20 years old and WELL is only 6 years old, it is also worthwhile to compare whether both

systems achieved similar attention at the beginning of the development. Line graph were used here to the trend of growth. This graph also convey the information that WELL is as reliable as the LEED, designers or developer could use this rating system without doubt.

|All-Together Comparison|



Growth Trend: LEED and WELL share the same projects growth trend in the early stage.

Given the fact that, LEED is a fully developed rating system, origineted in 1993. However, WELL is only six year old. By comparing the first-six-years of the development, we could see that WELL has a similar growth trend as LEED in its early years. Developers begin to adopt this rating system, and increasing numbers of projects use it, which indicates that nowaday deisgners not only care about energy, but also well-being of the residents.

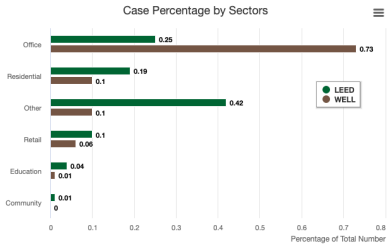
ii) Then, I used two parallel bar graphs to compare the types of buildings and the certified levels.

Most of the successful WELL projects are offices, however LEED have a wider range of building types. Viewers can choose rating systems based on their project types.

Based on the certification level (Platinum, Gold, Silver, Certified), the higher credits the project gets, the higher certification level it will achieve. It would be challenging to reach a higher level. So, from the second parallel bar graph, it seems harder to reach higher credits for WELL, since only 13% of the projects were certified as platinum. Viewers can make their decision based on budget or requirement of their projects.

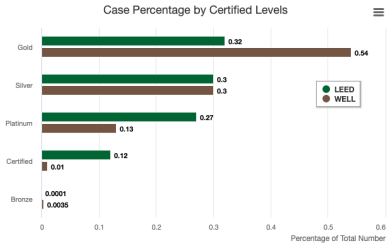
Types of Buildings: Various types of projects achieved LEED; Most of the WELL project are office building.

The function of the building is highly related the design strategies that could be used for sustainable design. Under some circumstance, the design strategies for creating the healthy environment could be difficult for some types of the building. So, based on the current information of projects, most of the WELL projects are office, which is a well-studied, small and easy to manipulate spaces. However, for LEED, various types of buildings used this rating system, especially for those projects with specical funstions (others). From this aspect of view, WELL need to increase its possibility of application in other types of buildings.



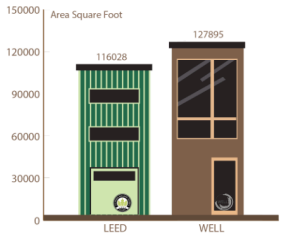
Certified Levels: It's harder to achieve higher certified level for WELL compared to LEED.

For both the systems, buildings can be certified as Certified, Silver, Gold or Platinum. These buildings must be constructed, maintained and operated in a sustainable, or resource efficient, way. They should be healthy for their occupants and the environment and meet certain criteria. So the higher the level, the harder it will be. There are more projects certified as LEED Platinum compared to WELL Platinum, which means that it would harder to achieve higher credits for WELL, or more complicated strategies are needed to be done for higher certified level.



iii) Last but not the least, I used an iconological bar graph to show the average size of the project. The average project size of WELL is slightly larger than the LEED. The bars of the graph

are composed of two comical buildings, which is impressive without the exaggeration of the real data.



Average Area: The average area for LEED and WELL are relatively same.

Size of the project is also an important aspect when it comes to the design strategies. But, based on the data, the average area of projects for both rating systems are relativley similar, with a higher number for WELL. So, as a designer, you can try both systems for your design.

This is a final project of an information course in University of California, Berkeley, named Information Visualization and Presentation.

Data come from the project inventories of LEED and WELL.

May 2020, Berkeley,CA

4. Data Sources

There are several datasets I used to accomplish my goals. Data about the performance of green buildings came from a website report of the World Green Building Council. Dataset from a systematic review was used to show the key word frequency and relationships. Scoreboard of LEED and WELL are used for the criteria comparison. Two project directories, containing detail information about the buildings using the rating system, are used for the comparison.

4.1 World Green Building Council

The data used for showing the benefit of the green building came from the World Green Building Council, they analysis the benefit from different aspects. In their report, they pointed out that green buildings can reduce or eliminate negative impacts on the environment, by using less water, energy or natural resources.

Report URL: https://www.worldgbc.org/benefits-green-buildings

4.2 Literature data

The data used for the bar-arc graph came from Shi, Y. and Liu, X. (2019) 's study. The purpose of their study is to systematically analyze and visualize the status quo of green building. Based on Web of Science (WoS), their paper analyzed the existing knowledge system of green building, identified keywords related to green building and their frequency of in order to reveal how research related to green building has evolved over time.

Source: Shi, Y. and Liu, X. (2019) 'Research on the Literature of Green Building Based on the Web of Science: A Scientometric Analysis in CiteSpace (2002-2018)', SUSTAINABILITY, 11(13). doi: 10.3390/su11133716.

4.3 Scoreboard or Checklist

For green building rating systems, scoreboards/checklists are used for tracking their project goals and progress as well as the final credit calculation. The link to the scoreboards /checklists are shown as following:

LEED:

BD+C: https://www.usgbc.org/resources/leed-v4-building-design-and-construction-checklist

ID+C: https://www.usgbc.org/resources/leed-v4-interior-design-and-construction-checklist

O+M: https://www.usgbc.org/resources/checklist-leed-v4-building-operations-and-maintenance

WELL:

WELL v2: https://v2.wellcertified.com/v/en/overview

4.4 Project Inventories

In this visualization, I used LEED building standard project inventory from 2000 to 2019 and WELL building standard project inventory from 2014 to 2019. The detailed information about the variables in the inventories is shown in **Table 2**.

Table 2 WELL building standard project inventory from 2000 to 2019

NO	Variable	Note
1	Project Name	**14,600 records (LEED)/ 4300 records (WELL)**
2	Street	Street name with street number
3	City	More than 100 hundred cities
4	State	Only for the project in the US
5	Country	More than 30 countries
6	Certified level	4 certified level: Platinum, Gold, Silver, Certified
7	Area	Gross Square foot of the project
8	Project type	A project may have more than one project type, data transformation is needed
9	Certified data	Year-Month-Day

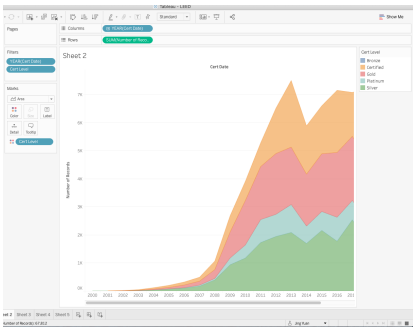
LEED Inventory URL: https://www.usgbc.org/projects

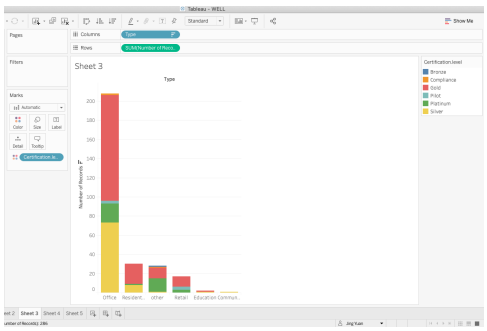
WELL Inventory URL: https://www.wellcertified.com/directories/projects

5. Tools

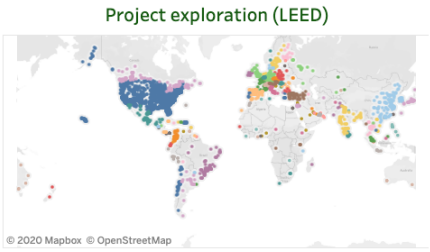
5.1 Tableau

I used Tableau for two purposes. First, exploratory data analysis of the two project inventories.



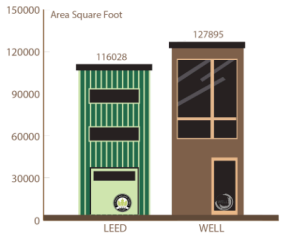


Second, I used Tableau to plot the geographic distribution of the projects.



5.2 Illustrator

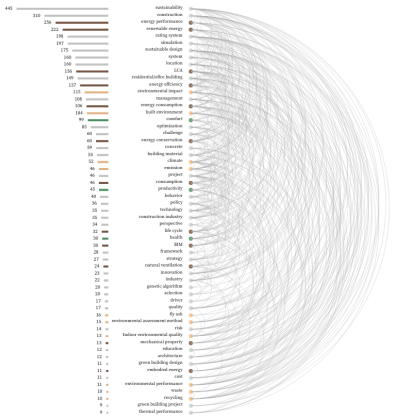
I used Illustrator to put all the logos of the rating systems together and make the graph for the size comparison.

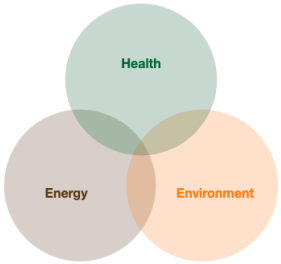


5.3 D3

I used D3 to make the interactive bar-arc graph and the venn graph. (Note: I am doing this project by myself, so I borrow one graph I made for the homework here)

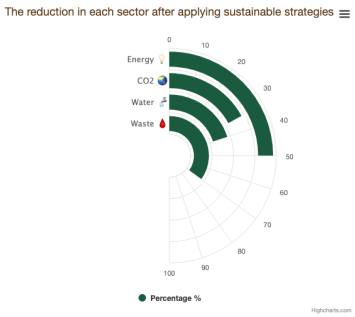
Showcase of the interactive graph (URL):
https://drive.google.com/file/d/1BEwhq4Ts_V6E3ukOe-MCIj0iXaPaVdQw/view?usp=sharing

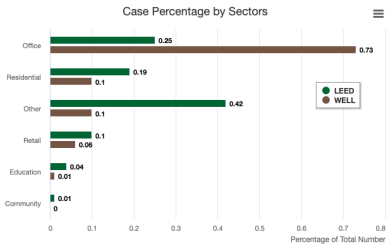




5.4 Highchart

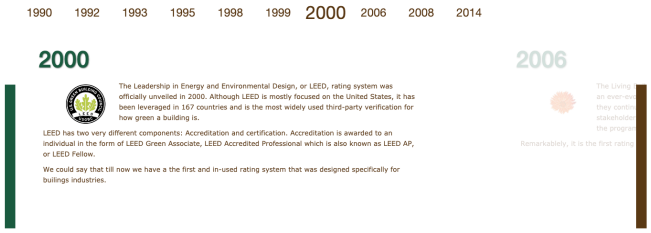
Highchart is a great tool, in which there are a lot of pre-made graphs that I can use by only making small changes. So, I used this tool to make the half-circle graph and the parallel bar charts.





5.5 Timeline

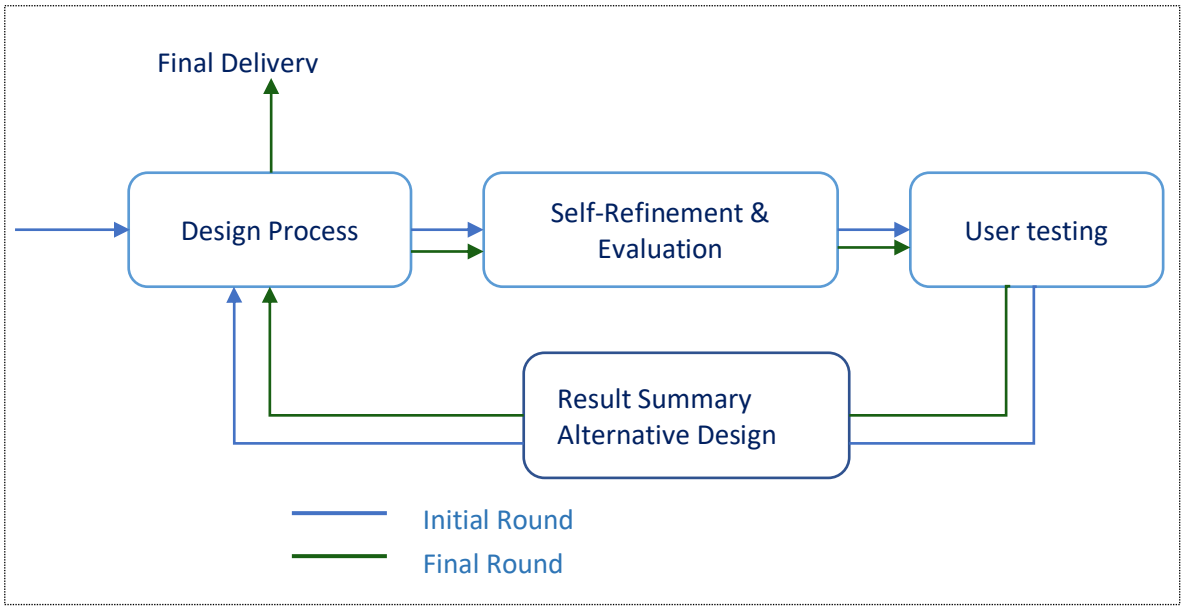
I adopted the timeline design from a blogger, “A Pen by Alberto”, and made minor changes to the code to satisfy my need.



Original code of the timeline: https://codepen.io/Naasa21/pen/qdxKMo/

6. Usability tests

I did this visualization by myself. So, the evaluation process is of vital importance for me. I designed an evaluation strategy which including self-refinement and 2 rounds user testing.



6.1 Initial Round: After design process

6.1.1 Method

In the user tests, I primarily used the online survey along with a short and causal post-test interview. Each usability experiment contained three main study periods: pre-interaction, interaction and post-interaction. Before the beginning of the user testing, I let each of the participant look over the consent form and gave me an oral agreement on conducting the experiment with them. Three researchers were selected from the Center of Built Environment (CBE) at University of California, Berkeley, aged between 30 ~ 40 years old with at least Master's degree in engineering or architecture. In order to prevent bias, I did not collected any personal information from participants. Moreover, before testing, none of the participant have ever looked at this website design or gave any suggestion on the design or data analysis. The procesure of the user testing is shown as following (**Figure 1**):

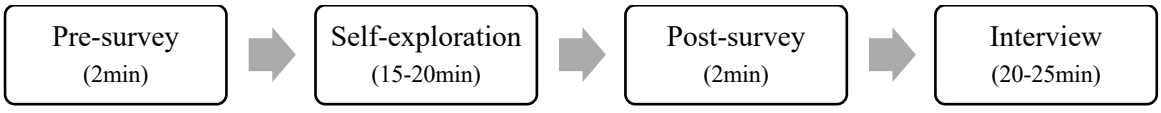


Figure 1. Test Procedure

Pre-interaction: Before participants interact with web pages on their own, they had to answer 6 questions (questions are shown in the following **Table 2**) about green building rating systems based on their experiences. From this test result, I will know how much all the participants know about the green building performance and green building rating systems.

Table 2 Survey Question List

NO.	Survey questions
1	Building consume what percentage of total electricity energy?
2	Generally, how long do we spend in the indoor environment? (Normally)
3	Compared to traditional building, Green building have the advantage of reducing:
4	Please select three Pillars (focus or aspects) of Green building rating system
5	LEED and WELL are two green building rating system, they are used:
6	Compared to LEED, the highlight of WELL is:

Interaction: Then, the participant would go through the web page on their own and they needed to share their screen at same time. Their behaviors were monitored while they are exploring, given the fact that some of the design that I made might be ignored when users played with the website without instructions.

Post-interaction: Finally, in the post-interaction period, they had to close the web page and were asked to answer the 6 questions again along with 3 design questions about this web page (**Table 3**). After the post-survey, I opened up the webpage again, shared screen with them and interviewed each participant about their feeling of this interface and suggestions for future improvement. Oral questions including but not limited to: If you were ask to make at least one changes to the website, which part do you want to change? What will you do? Do you notice that you can click the long bar of the timeline section? Can you read this spider chart? Etc..

Table 3 Addition Questions in Post Survey

NO.	Survey questions
1	Which aspects of LEED and WELL is NOT compared in this web page?
2	According to the web page, does size of you project matter, when you make decision between LEED and WELL?
3	There are three part for this Web site, which part do you like most and which part do you like least. For the least part, do you have any suggestion of improvement?

6.1.2 Results

6.2.1 Results of the quantitative measures

Due to the design of the survey, each participant will answer questions listed in **Table 4** twice before and after the interaction. In order to find out whether there are improvements in their knowledge of green building rating systems, I calculated the ratio of the number of people answered correctly to the total number of participants as ***Accuracy*** for both pre and post survey. From the results showed in **Table 4**, it is obvious that the accuracy of each questions from post survey are higher compared to the corresponding questions from the pre survey. The results tell us that after interacting with this webpage, participants have a clearer idea about this topic, but might perceive each part of the information differently.

For Question 1, all participants estimated the average energy consumption of buildings correctly, which testify that they are building energy experts. But for the Question 2, all participants lost point on this question by underestimating the total hour we spent indoor during normal condition. After this intervention, they should have realized that people usually spend 90% of their time indoor, even without the Stay-in Place order during the pandemic. For Question 8, two out of tree participant failed, which indicated that some improvement needed to be done for the corresponding part of design.

Table 4 Survey Results - Quantitative

NO.	Survey questions	Accuracy	
		Pre	Post
1	Building consume what percentage of total electricity energy?	100%	100%
2	Generally, how long do we spend in the indoor environment? (Normally)	0%	100%
3	Compared to traditional building, Green building have the advantage of reducing:	66.70%	100%
4	Please select three Pillars (focus or aspects) of Green building rating system	33.30%	67%
5	LEED and WELL are two green building rating system, they are used:	66.70%	100%
6	Compared to LEED, the highlight of WELL is:	33.30%	100%
7	Which aspects of LEED and WELL is NOT compared in this web page?	-	67%
8	According to the web page, does size of you project matter, when you make decision between LEED and WELL?	-	33.30%

6.2.2 Results of the qualitative measures

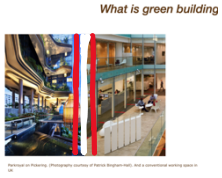
I also add a type-in question at the end of the post survey to see how much they remember about the webpage by letting them point out the best and worst parts of the interface without seeing the design of the webpage. The summary of the comments is shown in **Table 5**.

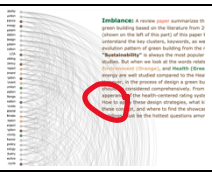
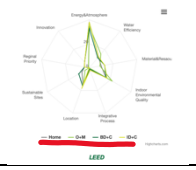
Table 4 Survey Results - Qualitative

NO.	Survey questions	Comment Summary
9	There are three part for this Web site, which part do you like most and which part do you like least. For the least part, do you have any suggestion of improvement?	• Best: the narrative infographic at the beginning of the page; the parallel comparison at bottom; the bar-arc graph • Worst: the spider plot; the timeline

In addition to the ranking of each element within the webpages, more suggestions and feedbacks came from the interview. The key take-aways are summarized in **Table 5**.

Table 5 Interview Results

NO.	Problems	Screen shot of the problem and possible solution
1	The picture of green building and non-green building is confusing	 Use blank space to sperate two pictures or put pictures into two lines.
2	It is not proper to use traditional building against the green building. Because traditional building also refers to historical buildings.	Change “Traditional building” to “Non-green building”.
3	It is hard to find that I can interact with this Timeline. The high bar is confusing, if no instruction.	 Add text or icon to inform user that they can click the high bar or year to explore.
4	Maps fail to show in narrow screen	 Change the display method of the map from horizontal to vertical
5	Key point of each paragraph or comparison aspect is obscure.	Put summary sentences for each paragraph by using the structure heading, highlights and main context.

NO.	Problems	Screen shot of the problem and possible solution
6	The long paragraph under the “THE COMPARISON BETWEEN TWO RATING SYSTEMS ” is too long to read.	 Separate two paragraph into sub-paragraphs. And introduce the LEED and LEED system indifferent parts and highlight each system.
7	The color of the bar-arc graph’s arcs is too dark when un-selected which make it hard to read the words on the right.	 Use lighter color for the arcs under un-selected condition
8	Four items listed below the spider chart of LEED is confusing.	 Add detailed note for each of the items below the spider graph
8	Font size is too small	Use larger font size

6.1.3 Improvement

Part 1: Introduction of green building and green building rating systems

The narrative infographic used to explain the energy use of buildings is memorable and clear which is mentioned by all the participants. The biggest problem is the way I compare the traditional (non-green) and green buildings. First of all, I need to change the way I call buildings without the implement of energy, environment and health strategies, from traditional to non-green. Then the layout of this part is messy no matter the placement of the pictures or the arrangement of the context. So, I give clear definitions for both green and non-green buildings and use more distinguished picture to show the real built environment separately.

Part 2: Introduction of the development of the green building and the key pillars of green building rating systems

There are three major design strategies used here: timeline used for rating system history exploration; venn graph for showing the three pillars of the rating systems, and the bar-arc graph for key word ranking. More instructions are needed to highlight the interactivity of the timeline, given the fact that during the user test, only 1 out of 3 participants click on the “year” or the “high-bar”. I add texts (e.g. Click high bar to go to the next year) or icons (e.g. Arrows) beside the timeline or below the former descriptive paragraph to let the user know

the way of interaction. For the bar-arc graph, I changed the color of the arc and the size of the text based on the users test.

Part 3: The comparison between two rating systems: LEED and WELL

This is the major part of the interface. I compare two rating systems from different aspects. After interviews, the biggest problem existed is lack of highlight of the results. For example, I mentioned the main topic of each comparison, but users need to spend a long time on reading the words or figure out the findings of each comparisons by themselves. This could be a problem for users who are not a fan of reading or lack of professional training on reading graphs. To improve the memorability of the comparison, I add a short sentence as the brief description of the findings. Moreover, the last infographic used for the size comparison is problematic, 2 out of 3 people fail to get the information that the average size of the LEED and WELL projects are relatively same and we do not need to consider size of the project when we choose rating systems. To solve this problem, I add a summary sentence to inform user that the size does not matter when you choose between LEED and WELL.

6.2 Final Round: After adjustment

6.2.1 Method

In the final round of user tests, I primarily used a short and causal interview. Each usability experiment contained two main study periods: self-exploration and interview. Participants who were selected in the initial round of user test were invited again for the final round of user test. (**Figure 2**)

Figure 2. Test Procedure

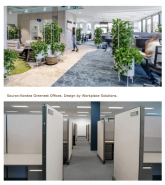
Self-exploration: The participant would go through the refined web page on their own and they needed to share their screen at same time. Their behaviors were monitored while they are exploring.

Interview: After the self-exploration, I opened up the webpage again, shared screen with them and interviewed each participant about their feeling of this new interface and the adjustment I made based on their suggestion. Oral questions including but not limited to: Did xxx (problems) solved? How do you think about the new design? Any addition suggestions? Etc..

6.2.2 Result

Feedbacks came from the interview are summarized in **Table 6**.

Table 6 Interview Results

NO.	Feedbacks	Screen shot of the part
1	The separated view is better to understand.	
2	The definition of the LEED and WELL are useful for the understanding of the following comparison	
3	Summary sentence is great, the whole idea get clearer.	
4	The vertical layout works for my small screen.	
5	Suggestion for usability under larger population: All the improvement state above will solve most of the usability problems. However, two potential problems will happen, if this website were tested or used by a larger population of designers and developer without professional training on reading arc graph and spider graph. So, some detailed instructions or guide are needed along with these two graphs. For instance, instead of using interactive arc graph, I could display a video in which I play with arc graphs by hovering key words that I intended to show. Or for spider graphs, I will remain the spider graphs due to the graph of the interface, but I can create a link to an alternative parallel bar graph in case they need similar way of data visualization.	

7. Acknowledgement

Overall, I found the experience of completing this project to be highly educative. Not only do I used the skills that I learnt from *the Information visualization and presentation*, but also have a change to summarize all the knowledge that I know about green building rating system and put them all together in a perfect shape. Some valuable takeaways got in the process are mentioned below:

- **Group work.** In order to have an impressive visualization, group work is of vital importance. I did this visualization by myself, but if I would do this with more peoples, I will save a lot of time, have better design strategies and apply more complicated strategies.

- **Investigate before implement.** I did this visualization since mid-March. At that time, I only know how to use Vegalite and Tableau, so my design was limited to the tool I know. In the following courses, I get to know how to use Illustrator and D3, so I am able to make beautiful narrative figures and interactive graphs. Thus, some adjustments were made to my initial design of the web page, such as add a bar-arc graph.

- **Iteration really helps**. I designed an evaluation loop to help me with the iteration of the design which is supper helpful. I did a lot of adjustment based on the results and feedbacks. I would say that without the iteration, my design will be pale and illogical.

Many thanks to Professor Marti Hearst and our Teaching Assistant Nithya Ramgopal for your suggestions. And Thanks for those building science researchers who participate in the user tests for giving my valuable advice.

8. Links to documents

1) URL to the final visualization:

https://jingyuan1011.github.io/

2) URL to the final visualization showcase video:

https://drive.google.com/file/d/1l507UsZVTP4DhPSX2MVsVZ_G2-wrMWqO/view?usp=sharing

3) URL to the code on Github:

https://github.com/JINGYUAN1011/JINGYUAN1011.github.io

4) Link to Pre and Post survey

Pre-survey URL: https://forms.gle/3sDe1bSaN1hPFqo37

Post-survey URL: https://forms.gle/MuXqFTvKmsKnvkEf9