A Quantitative Study on the Colour of City Landmark Landscape Architectures

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Abstract. City landmark landscape architecture is a production of urban development to a certain historical stage, delivering dual functions: identification and sightseeing, which is a significant component of urban construction. Colour is the main media for the landscape architecture to identify itself and is often subjectively experienced by the public and designers. However, the subjective perception cannot lead to a more scientific, quantitative, and repetitive research showing its limitations. In this paper, a quantitative study on the colour of landmark landscape architecture is undertaken and demonstrated via a case study: Sacred Heart Cathedral Jinan. The colour data of five representative components (circle window, apex window, wall decorative symbol, decorative stone carving, and decorative stone beam column) on the main façade of the cathedral are quantitatively collected including HSB, RGB, CMYK and CIELab in which the HSB data that responds to human eyes are used to explore the colour patterns at different time. With different identification degrees, it objectively shows whether a component can be explicitly viewed and whether a specific time is good for sightseeing. The methods in this paper are scientific-based, quantitative, and repetitive, thus providing the methodological support for designing and experiencing the future city landmark landscape architecture.

1. Introduction

The city landmark landscape architecture is a symbol of a city, which is not only the landmark building itself, but also represents the cultural traditions and regional characteristics of the city, showcasing its history, culture, technology, economy, and social development. Therefore, landscape architecture is a significant component of city construction. In the age of ‘Design leads the future’, in addition to be an outstanding project, a successful landscape building may also generate, vitalise and symbolise a city in which Guggenheim Museum Bilbao is one of such examples \cite{1}. However, as an effect of global urbanisation, worldwide city cultures tend to become similar. In this respect, how to design city landmark landscape architecture has become the focus of designers, urban constructionists, and academic scholars. Based on current literature, much attention has been paid to the discussions of design problems, such as design ideas, technology and methods. Quite a few studies focus on the built landscape architecture which mainly use the subjective evaluation methods. There is a significant gap in quantitative studies based on objective evaluation and digital technology.

Colour is a necessary component of design and is the first element to stimulate human’s visual response to objects. According to the colour studies, when human initially observer an object, colours
capture 80 percent of the attention where only 20 percent are left for the morphology of the object. This situation normally lasts 20 seconds after which focus on the morphology will increase to 40 percent where the colour will decrease to 60 percent. After 5 minutes, the focus on the colour and morphology will be equal. Therefore, it is concluded that colour, as the first element for humans to perceive objects, has a particular effect on human’s perception [2]. For a long time, the colour design of the landscape architecture is based on the subjective perception of designers. However, as technology develops, especially the development of objective measurement and digital technology, colour study has been involved in a quantitative and digital area where colour can be computed as binary digits and recognised by computers for encoding, computing, and analysis through new technology and equipment [3]. The quantitative description, analysis and computing methods have gradually made contribution to the colour related areas, which can also be applied to landscape architecture. Through digital technology, the colour codes of significant landscape buildings can be obtained as to analyse the colour patterns at different time. Moreover, this method provides guidance regarding the modern design practice, urban architecture, and landscape and façade design [4].

In this paper, Sacred Heart Cathedral Jinan is taken as an example to quantitatively describe and analyse its façade colour via digital measurement and technology. By understanding how colour can be perceived and influenced, a constant setting is made, and four kinds of colour modes data are quantitatively collected. When the colour mode that is most closely linked to human's eyes is identified and analysed, the colour change of Sacred Heart Cathedral in a day can be objectively obtained, which demonstrates the relationship between its façade forms and colours. The methods can provide guidance for sightseeing Sacred Heart Cathedral, providing theoretical and methodological support for the design and research of city landmark landscape architecture.

2. Research Theories and Method

2.1. Colourvisual Perception
According to Sir Isaac Newton’s colour theory, the visual perception of colour in the human eye is an interaction of light and colour. A particular colour an object has depends on the colour of the light leaving their surfaces, which is processed and distinguished by the human eye at different wavelengths. The referred colour is the visual perception of the human retina on the colour of the light that is reflected by the object.

According to physics studies, human visible light is a kind of electromagnetic waves whose different wavelengths are perceived as different colours. The range of wavelengths that humans can perceive is approximately from 390-700nm, known as visible light [5, 13]. The mentioned colour theory and physics studies provide theoretical foundations and quantitative descriptions for the colour study on the landscape architecture in this paper.

2.2. Colourvision and Influence Factors
The various colours that objects have depend on the environment and many other factors. Current studies have indicated that with the same light source, different degrees of absorbing lights result in different colours; even with the same object, they show different colours if they are illuminated by light sources of different wavelengths. In essence, the colour is determined by the spectrum of the illuminating light, which is the remaining light reflected by the object, called the object colour [6]. In other words, the object colour is influenced by the light source. In addition to this, current studies also indicate that complex environments, including the brightness (bright or dark), colour and light source, also influence discerning the colour of the object. It has been proved that the object colour stays stable under the standard sunlight. Therefore, the effect that the colour of an object keeps stable illuminated by the standard sunlight is called the colour constancy [7,8].

This paper integrates different factors affecting the colour of landscape architecture to determine the quantitative data acquisition methods and procedures.
2.3. Colourgamut

Colourgamut is a colour reproduction system to code the range of colours [18], which has been widely applied in computing diagram processing. It describes a full set of a particular colour and specific figures in the given set. In the colour research field, colourgamut identifies the colour range in a given colour space or an output equipment [9]. In the design filed, applications of colourgamut have a long history, and Munsell Colour System is one of the most representative colour reproduction systems. It uses H, L, and C to denote hue, brightness, and saturation, respectively [10]. In 1931, the CIElab colour measurement global standard is established in which L represents brightness, a represents the colour range from red to dark green, and b represent the colour range from blue to yellow [11]. Although this standard improves the accuracy of colour reproduction [12] and these two systems construct a digital model to code colours, they are independent on the colour printing systems.

As the digital technology develops, colourgamut has been widely used in the computing diagram field. The colour gamut has also been digitalised and closely linked to the information technology, digital design and digital printing. RGB colouring is a commonly used colour reproduction system, which is mainly in charge of illuminative light, television, and computer monitors. It is created by mixing together light of two or more different colours [13] in which R represents red, G represents green, and B represents blue. HSB colour modes are to respond to human’s eyes where H stands for hue, S stands for saturation, and B stands for brightness [14]. CMYK colouring is to use dyes, inks, pigments, or filters to absorb some wavelengths of light and not others [13].

This paper utilises colour gamut to quantitatively describe and analyse the colour of landscape architecture. The results can be used to support the colour design of the city landmark landscape architecture.

3. Research Process and Results

3.1. Research Object

The research object in this paper is Sacred Heart Cathedral (Hongjialou Cathedral), one of the landmark landscape buildings in Jinan, located in the east of Jinan city, Shandong Province, China. Constructed in 1901, it is a typical Roman Catholic Church with Gothic Revival style derived from the 1200s to 1600s, which is honoured as one of the three large cathedrals in China [15,16]. Sacred Heart Cathedral is not only the window for China to exhibit its western style architecture, but also represents the modern architecture in Jinan that has witnessed the cultural traditions of Jinan and a blend of mixed cultures. The cathedral was designed by the famous architect Franciscan Bro. Corbinius Panger and built in three years. The total gross building area is approximately 2600 meters square. Sitting in the east and facing the west, with narrow front and wide back, numerous edges and corners, and windows and doors, it is mainly made up of black brick and stones, delivering an enormous volume. The basic layout of the cathedral is a Latin cross with two tall towers, a typical Gothic architectural style. Each tower is about 60 meters high with two domed pointed arch roofs. The three main doors also have pointed arches with decorative stone carving [15]. Not many buildings are around the cathedral, therefore, this paper only considers the building itself and focuses on its main façade that characterises its Gothic architectural style. The cathedral has a various style in relation to its structure and decorations, five representative components on the main façade are selected to collect the colour sample data, as shown in Figure 1. The study combines three ways to collect data: filed photographs (Canon 7D, Alice colour card passport), quantitative colour data (Colour Checker Passport, Adobe Photoshop Lightroom, Adobe Photoshop, Colour Schemer studio), and colour observations.
3.2. Quantitatively Collecting Colour Data

The wall of the Sacred Heart Cathedral main façade is made up of black brick and stones, in which the colour grey is normally used to describe the visual perception. However, this description lacks objective data support and cannot discern the grey colour differences regarding its hue, saturation, and brightness. Moreover, it cannot explicitly describe the colour change patterns at different time, weather and temperature [17]. In order to make the colour design results repetitive, this study sets several areas to collect the graph samples within the fixed position and viewing angles. The collected graph samples are quantitatively transformed into digital data for description and analysis. The study is conducted as the followed three stages.

3.2.1. Graph Sample Collection Conditions.

According to current research, the most ideal illumination condition for outdoor sightseeing is D65 (6500k in terms of the colour temperature). Without any other artificial illumination, it can meet this standard from 10 am to 2 pm in the day [18]. This study is conducted at this time period to ensure all the graph samples are under the same degree of light illumination.

To avoid the effects of weather on the colour measurement, all the graph samples are collected in cloudless and sundry days at the level 4 of weather forecast [13].

The main façade of Sacred Heart Cathedral is well preserved and represents the classic Gothic style in terms of its space and volume, especially the central parts of the façade. Therefore, those parts are set as the graph samples in this study.

3.2.2. Graph Sample Collection

Step 1: Cannon 7D is used to take photographs and the tripod is set 25 meters far from the cathedral main façade;

Step 2: Fix the camera on the tripod and make the height of the camera 1.5 meters high to represent the human view point;

Step 3: Adjust the tripod to allow 65 degrees of elevation;

Step 4: From 10 am to 2 pm in the day, photos are taken every hour in which 5 samples of each component are collected at this time period. Note before taking photos, photos of the colour card should be taken first;

Step 5: Colour Checker Passport and Adobe Photoshop Light room are used to amend the colours based on the photos of the colour card passport. This is to rectify the data errors caused by the light source and adjust the colour white balance to ensure the colour accuracy of graph samples;

Step 6: Double check the graph samples after colour adjustment to make sure all the colours are relatively realistic and accurate, so they can be used for quantitative analysis in a later phase. Mark all the collected graph samples, as shown in Table 1.
Table 1. Marking the graph samples. (8 August 2018)

| Time   | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 |
|--------|-------|-------|-------|-------|-------|
| Graph Sample | ![Sample1] | ![Sample2] | ![Sample3] | ![Sample4] | ![Sample5] |
| Mark   | T1    | T2    | T3    | T4    | T5    |

3.2.3. Quantitatively Collecting the Colour Data

Undertake the colour analysis of the final graph samples.

Step 1: Use Adobe Photoshop to rasterise the graphs and categorise them as pixels at 100 units per meter square. Amplify the parts;

Step 2: Use Colour Schemer studio to compare the colour change of the five components that represent the Gothic style. We have selected five areas/components and collect the graph samples five times, so in the end we have 25 samples. Table 2 lists the location of the five components and associated marks;

Table 2. Colour sample locations and associated marks.

| ColourSample Locations | Circle Window | Wall decorative Symbol | Apex Window | Decorative Stone Carving | Decorative Stone Beam Column |
|------------------------|---------------|------------------------|-------------|--------------------------|-----------------------------|
| Sample Mark            | Sample 1      | Sample 2               | Sample 3    | Sample 4                 | Sample 5                    |

Step 3: Use Adobe Photoshop and Colour Schemer studio to collect the HSB, RGB, CMYK, and CIELab data of the 25 samples, as shown in Table 3.

Table 3. Colour sample, data, and mark.

| Sample Mark | Time | Colour sample | HSB     | RGB     | CMYK    | CIELab  |
|-------------|------|---------------|---------|---------|---------|---------|
| T1          | 10:00| H:0°          | R:204   | L:82    | C:23%   |
|             |      | S:0%          | G:204   | a:2     | M:18%   |
|             |      | B:80%         | B:204   | b:2     | Y:17%   |
|             |      |               |         |         | K:0%    |
|             |      | H:48°         | R:91    | L:38    | C:70%   |
|             |      | S:6%          | G:90    | a:0     | M:63%   |
|             |      | B:36%         | B:86    | b:2     | Y:63%   |
|             |      |               |         |         | K:15%   |
|             |      | H:70°         | R:141   | L:59    | C:52%   |
|             |      | S:4%          | G:142   | a:1     | M:42%   |
|             |      | B:56%         | B:136   | b:3     | Y:44%   |
|             |      |               |         |         | K:0%    |
| Time | Color Information | H: ° | S: % | B: % | R: | G: | B: | L: | a: | b: | C: % | M: % | Y: % | K: % |
|------|-------------------|------|------|------|----|----|----|----|----|----|------|------|------|------|
| 11:00 | T2 | H:25 | S:16 | B:53 | R:136 | G:123 | B:114 | a:4 | b:7 | Y:53 | K:1 |
|      |     | H:26 | S:6  | B:43 | R:110 | G:106 | B:103 | a:1 | b:2 | M:58 | Y:56 | K:5 |
|      |     | H:0  | S:0  | B:80 | R:204 | G:204 | B:204 | a:0 | b:0 | M:18 | Y:17 | K:0 |
|      |     | H:300| S:8  | B:33 | R:83  | G:76  | B:83  | a:4 | b:3 | Y:70 | K:19 |
|      |     | H:44 | S:11 | B:55 | R:139 | G:135 | B:124 | a:0 | b:7 | M:46 | Y:50 | K:0 |
|      |     | H:22 | S:7  | B:45 | R:115 | G:110 | B:107 | a:2 | b:7 | M:57 | Y:55 | K:3 |
|      |     | H:252| S:5  | B:36 | R:89  | G:88  | B:93  | a:1 | b:3 | M:65 | Y:58 | K:12 |
| 12:00 | T3 | H:215| S:10 | B:76 | R:175 | G:183 | B:194 | a:-1| b:-7| Y:19 | K:0 |
|      |     | H:206| S:9  | B:71 | R:165 | G:174 | B:181 | a:-2| b:-5| Y:24 | K:0 |
|      |     | H:220| S:3  | B:36 | R:88  | G:89  | B:91  | a:0 | b:-1| Y:59 | K:13 |
|      |     | H:10 | S:21 | B:34 | R:86  | G:71  | B:68  | a:6 | b:4 | M:70 | Y:68 | K:27 |
|      |     | H:345| S:2  | B:65 | R:166 | G:162 | B:163 | a:2 | b:0 | M:35 | Y:31 | K:0 |
|      |     | H:220| S:2  | B:67 | R:167 | G:168 | B:170 | a:0 | b:-1| Y:29 | K:0 |
| 13:00 | T4 | H:220| S:2  | B:67 | R:167 | G:168 | B:170 | a:0 | b:-1| Y:29 | K:0 |

T2 and T3 images are shown, each with a table of color information and a diagram.
### 3.3. Quantitative Analysis on Colour

Although the colour of the historical landscape building can be objectively obtained via the graph samples, how it can be used to support urban construction needs to be quantitatively analysed. As HSB is response to human eyes, this colour mode is selected for further analysis in which 25 samples of HSB data are quantitatively analysed to explore their effects on viewers.

| Time | H: | S: | B: | R: | G: | B: | L: | a: | b: | C: | M: | Y: | K: |
|------|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 14:00| 225° | 10% | 49% | 114 | 117 | 126 | 49 | 0 | -5 | 63% | 54% | 45% | 1% |
|      | 29° | 18% | 71% | 182 | 165 | 149 | 69 | 4 | 11 | 35% | 36% | 40% | 0% |
|      | 27° | 15% | 23% | 59  | 54  | 50  | 23 | 2 | 3  | 75% | 73% | 74% | 74% |
|      | 0°  | 0%  | 50% | 127 | 127 | 127 | 53 | 0 | 0  | 58% | 49% | 46% | 0% |
| T5   | 30° | 8%  | 69% | 244 | 234 | 224 | 93 | 2 | 6  | 6%  | 10% | 13% | 0% |
|      | 28° | 31% | 16% | 42  | 35  | 29  | 14 | 3 | 5  | 77% | 77% | 82% | 60% |
|      | 34° | 17% | 69% | 176 | 163 | 146 | 68 | 3 | 11 | 37% | 36% | 42% | 0% |
|      | 37° | 30% | 28% | 71  | 63  | 50  | 27 | 2 | 9  | 71% | 69% | 79% | 39% |
|      | 60° | 13% | 30% | 76  | 76  | 66  | 32 | 2 | 6  | 73% | 65% | 72% | 28% |
3.3.1. Figure 2 Shows the Saturation Trend of the Five Samples at Different Time.

![Figure 2](image)

Figure 2. The saturation trend of the five samples at different time

Between 10 am and 2 pm, the colour saturation of the five examples changes dramatically showing that these architectural components greatly stimulate eyes. Therefore, all these parts can be perfectly viewed if tourists sightsee at this time period;

Between 1 pm and 2 pm, there is an increasing trend for 4 colour samples while only Sample 3 has a deceasing trend. This means at this time period, the identification degree of the apex window is decreasing, while other parts, circle window, wall decorative symbol, decorative stone carving, and decorative stone beam column, have an increasing identification degree in terms of their saturation;

Between 10 am and 11 am, the saturation change of Sample 1, 2 and 5 is minor compared to Sample 3 and Sample 4. In other words, the identification degree of the circle window, wall decorative symbol, and decorative stone beam column is weaker than that of the apex window and decorative stone carving;

Between 10 am and 2 pm, there is no saturating value overlapping (different saturation values at the fixed time) between all the five samples, which means all the five components can be explicitly identified. Therefore, it is ideal for sightseeing at this time period in which all the five parts can be overall viewed by tourists. We also find that in another time there is also no overlapping between all the five samples. However, it is not easy to get the accurate time. It is recommended to tour the cathedral at the fixed time shown in this paper.

3.3.2. Figure 3 Shows the Brightness Trend of the Five Samples at Different Time.

![Figure 3](image)

Figure 3. The brightness trend of the five samples at different time

Between 10 am and 2 pm, the brightness values of other four samples change more frequently than Sample 1. It means at this time period, the apex window, wall decorative symbol, decorative stone beam column, and decorative stone carving significantly stimulate the eyes which is good for sightseeing;

Between 10 am and 11 am, the brightness change of the five samples is very minor, so their identification degree at this time period stays the same;
Between 10 am to 2 pm, there is no brightness value overlapping (different brightness values at the fixed time) between all the five samples. Therefore, the circle window, apex window, wall decorative symbol, decorative stone carving, and decorative stone beam column can be clearly observed at the fixed time which is good for sightseeing the overall appearance of the main façade. We also find that in other time, there is no overlapping between all the five samples. It is recommended to tour the cathedral at the fixed time shown in this paper.

3.3.3. Figure 4 Shows the Hue Trend of the Five Samples at Different Time.

![Figure 4](image)

**Figure 4.** The hue trend of the five samples at different time

Between 10 am and 2 pm, the hue of the five samples changes dramatically. This means at this time period, all those parts stimulate the eyes of tourists. Therefore, it is a good time to be viewed at this time;

Between 10 am and 11 am, the hue change in Sample 1, 3, and 4 is minor compared to Sample 2 and 5, which means the circle window, apex window, and decorative stone carving cannot be explicitly recognised. In contrast, the wall decorative symbol and decorative stone beam column are easier to be recognised;

Between 12 pm and 2 pm, there is some overlapping in terms of the hue values at the fixed time. At 12 pm, the hue values of Sample 1, 2 and 3 are almost equal showing that the circle window, apex window, and wall decorative symbols have the same hue value. At 1 pm, the hue values of Sample 1, 2 are similar while those of Sample 3 and 4 are similar. In other words, at this time, the circle window and wall decorative symbol have the same hue and the apex window and decorative stone carving have the same hue. At 2 pm, the hue values of Sample 1, 2, 3, and 4 are similar so that these parts have the similar hue value.

4. Discussion

The quantitative study on the colour of the main façade of Sacred Heart Cathedral is to combine the light and colour theories and computer technology, analysing and generating the results. Different from human’s subjective perception and judgement, the study transforms the colour into digits for analysis [19] and the results can further support the landscape design practice. Conducted under a constant condition, the study collects three kinds of quantitative colour data, HSB, RGB, and CMYK, in response to human eyes, monitor display effects, and digital printing effects, respectively. CIELab data are also collected so they can be transformed and compared between each other.

Sacred Heart Cathedral, as the landmark landscape building in Jinan, has received continuous attention from the public, websites, and articles. This paper analyses the HSB data of the five samples in terms of their saturation, brightness, and hue. The results show that between 10 am and 2 pm, the hue, saturation, and brightness of the five samples change dramatically which means they significantly stimulate human eyes, so it is ideal to view the cathedral at this time period. At 2 pm the hue values of the samples are similar, however, they can still be recognised due to the differences of saturation and brightness. Furthermore, between 10 am and 2 pm, the hue, saturation, and brightness of the five samples are different from each at the fixed time except 2 pm (i.e. 10 am, 11 am, 12 pm, and 1pm). To
conclude, the preferred time to tour the cathedral as to have a memorial experience is 10:00, 11:00, 12:00, and 13:00.

If taking the samples into consideration, Sample 1 and 3 are component samples (circle window, and apex window) while Sample 2, 4, and 5 are decorative samples (wall decorative symbol, decorative stone carving, and decorative stone beam column). All the five samples represent the typical Gothic outlook of Sacred Heart Cathedral. If ignoring the change of brightness, the saturation degree of the apex window is greater than the circle window meaning that the apex window is easier recognised than the circle window. Among the wall decorative symbols, decorative stone carving, and decorative stone beam column, the decorative stone caring is most easily recognised. The colour data of the apex window is similar to decorative stone carving, so the identification degree of them should be the same.

Overall, the most easily identified components of the main façade of Sacred Heart Cathedral are the apex window and decorative stone carving. The results match the literature on the representative Gothic architectural style [15, 20]. Therefore, the design of the cathedral not only considers the shape, but also how the colour would add to the shape, making the shape more present.

5. Conclusion
This paper takes Sacred Heart Cathedral as the research object and conducts quantitative study on its colour using digital technology. HSB colour data are acquired in response to human eyes. By comparing the values of hue, saturation, and brightness of five components on its main façade, several conclusions are drawn as follows:

The quantitative analysis on the colour of the main façade of Sacred Heart Cathedral not only makes the design more scientific, but also provides objective data support for the landmark landscape architecture. More importantly, the colour data can be transformed and compared quantitatively, and it offers methodological support for the colour study on different landmark landscape buildings;

Between 10 am and 2 pm, the colour of the main façade of Sacred Heart Cathedral changes significantly, which to a certain degree can capture tourists’ attention and stimulate their eyes. Therefore, this time period is good for sightseeing. Among them, 10 am, 11 am, 12 pm, and 1 pm are easy to remember;

In terms of the representative components on the main façade, the apex window and wall decorative stone carving are most easily recognised for their colour and forms;

As a historical city landmark landscape building, the quantitative study on the colour of the cathedral is representative. The objective and scientific results can provide guidance for future landmark landscape design.

6. Research Limitations
The hue range is relatively small less than 45 degrees, so the study results do not apply to objects with a bigger hue range;

The selected research object in this paper locates in a relatively empty environment. Therefore, when tourists are close to the cathedral, they are not influenced by other factors. In this respect, the study is limited to a single building which is not applicable for a rich environment;

It has been proved that colour temperature is a significant variable in colour research. The research area is in Jinan, and the time period and colour temperature for research are set as 6500k, and 10 am to 2 pm, respectively. However, the colour temperature selection should depend on the actual condition and region where different regions, cities, or different landmark landscape buildings in the same area might need to set different colour temperature. In summary, it requires the field measurement before determining the study time period and colour temperature.

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