Digital Archiving of Perceptual Experiences of an Architectural Space with Computer-Aided Methods

Nan-Ching Tai[1] and Li-Wen Sung[2]

[1]National Taipei University of Technology, nctai@ntut.edu.tw
[2]National Cheng Kung University, sliwen@mail.ncku.edu.tw

Corresponding author: Nan-Ching Tai, nctai@ntut.edu.tw

Abstract. The importance of the preservation of historical heritage has been valued and emphasized, and efforts to achieve this have been continually made in many countries. Historical architecture is always in danger of being damaged or demolished by natural or man-made causes. Therefore, documenting heritage buildings with drawings and photos is important for archiving and preserving cultural heritage. Advances in digital imaging technologies such as photogrammetric modeling have enabled measurements of architectural heritage with high precision. However, the data archived for historical heritage still focuses on the physical properties of the architecture and less on the spatial perception of the visitor. The goal of this study is to develop a methodology to use technologies of digital photography to record the visual perception of an architectural scene that can invoke the perceptual memory of the heritage building. Hypotheses of frequency and maximal information were explored to identify the canonical perspective views of an architectural space. Behavioral mapping and a computer-aided method of Space Syntax were used to identify the canonical perspective views based on these two hypotheses. Perceptual studies were conducted, and the result revealed that the most frequently viewed scenes identified by behavioral mapping were most representative when subjects were asked to recall the architectural space. Meanwhile, computational analysis performed by Space Syntax can identify a location that is most frequently viewed and can view the most space. Possible methods to utilize technologies of digital photography to archive the perceptual experiences of an architectural space based on the viewpoint identified by the two approaches are proposed in this paper.

Keywords: Digital heritage, canonical view, space syntax, behavioral mapping, architectural heritage
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1 INTRODUCTION

The digital archiving of architectural heritage has focused on recording the physical configuration of architectural constructions in digital formats that can be preserved permanently and distributed easily. Based on the conceptual representational drawings of plans, sections, and elevations, along with the documentation of materials, construction, and assembly methods, the main purpose of archiving is to ensure that the knowledge gained by reconstructing architectural heritage is available to future generations [8],[11].

Digital photography utilizes sensors to capture light reflected from the environment through a camera lens to create images. The captured images can thus reflect the visual appearance of the built environment and thus provide a practical method to assist the archiving as the conventional photography. However, in the archiving of architectural heritage, photographs are more often used as supplements to conceptual information, such as the appearance of the materials or the details of the craftsmanship, and to a lesser extent as documentation on how an architectural space is intended to be experienced by visitors.

Recent developments in digital technologies of remote sensing and photogrammetric modeling further allow the use of digital photography to reconstruct three-dimensional configurations of architectural heritage with a textural appearance [6],[17]. Those novel approaches have been successfully applied to archive architectural heritages of different cultures and further enable an innovative spatial experience through panoramic video or virtual reality [3],[13],[18]. Although these novel interactive displays provide experiential ways of examining the archived data of the architectural heritage, they fall short of recreating the perceptual experience owing to the visual realism provided by the original archived image.

A high dynamic range (HDR) image is another recent trend in the development of digital photography. The related technologies of HDR photography advance the visual realism of digital photography [16]. An HDR photo can faithfully record and store the luminance distribution of the captured scene, thus providing a reliable archive of the perceived scene with physical accuracy [4]. Various tone reproduction methods were further developed based on human visual processing, allowing the tone-mapped images of an HDR scene to reproduce the visual perception of the captured scene [16]. As a result, the availability of HDR photography provides a possible solution to archiving the significant spatial experience of an architectural space.

The goal of this study is to develop a framework that incorporates the perceptual viewing experience into the digital archiving of architectural heritage. The established methods of behavioral mapping and the newly developed Space Syntax digital tool were used to investigate how to identify views that best represent the perceptual experiences of an architectural space. Perceptual studies were conducted to identify the types of architectural scenes that are most representative of a particular architectural space. To conclude this study, the methods used were compared, and a framework was developed to determine the appropriate point of view for scene recording or the appropriate perspective for photograph acquisition when archiving the perceptual experience of historical architecture.

2 METHOD

One of the intentions in architectural design is to configure the physical construction to create a particular experience in a space. For instance, the planning of the circulation often determines the point of stay, and thus creates design opportunities to frame the view with architectural elements. Given our own human visual perception of the world, the exact contribution to our memory regarding an architectural space relies on what we have seen. As a result, recording the perceptual experience of architectural scenes presented based on an architectural construction should be as important as the recording of the physical construction of historical buildings and monuments. However, an architectural space can be presented using an unlimited number of points of view.

Accordingly, the determination of viewpoints and the recording of their corresponding scene is the first question that needs to be addressed in this study.

2.1 Canonical View

A three-dimensional object can be viewed from many different perspectives. Object recognition studies have suggested that an object can be most easily identified from a particular view. This view is termed the canonical perspective or the canonical object view [15]. Many studies have been conducted to develop systematic methods to identify a canonical view of a 3D object, and they generally agree that the frequency and maximal information hypotheses can derive the canonical view of an object under investigation [5],[14]. The hypothesis of maximal information implies that a view that reveals most of the information of an object is preferred as its canonical view. Conversely, the hypothesis of frequency suggests that the canonical view requires the minimum amount of time for the recognition of the object because, having seen it many times, it is imprinted in a person's memory [5],[7],[14].

It is possible that both hypotheses contribute to the formation of a canonical view of a 3D object. However, an architectural space is an immersive environment that cannot be viewed in its entirety from within. Accordingly, the canonical view of an architectural space may be more relevant to the hypothesis of frequency.

To determine the canonical view of an architectural space based on the most frequently seen views, we experimented with two different approaches of behavioral mapping and Space Syntax. Perceptual studies were conducted to investigate whether a canonical view could invoke one's mental image of a particular historical architectural space, and to identify the method that is more reliable in determining the canonical view of the architectural space.

2.2 Selected Cases for Study

Two traditional temples located in Tamsui, Taiwan, were selected for the study. Both Longshan and Fuyou temples were built for and devoted to the folk religion. These historical Taiwanese folk religion temples were selected for three reasons. First, they are the major architectural heritage of the country, and many of them have undergone dramatic remodeling, with some even demolished. Thus, the digital archiving of this heritage has become imperative. Second, there is a specific route associated with the ritual ceremony performed within the temple, which predetermines the point of view of the believers. Third, the traditional folk religion temple has a simple and open layout that allows for the unobtrusive observation of human behaviors.

In addition, the two temples have similar configurations of the front and main halls with a courtyard in the middle, but their current preservation conditions are different. The Fuyou temple is located on a busy main street and has been remodeled with the use of a roof to cover the courtyard, while the Longshan temple is hidden in a traditional market and has been preserved in a state that closely matches its original construction. A comparison of the two selected temples can also reveal differences owing to their currently preserved conditions.

2.3 Space Syntax

Space Syntax is a scientific approach to theories and techniques used to analyze the spatial layout in relation to the various scales of human interactions and social effects [1]. One of its analysis tools is a visibility graph that can reveal different perceptual aspects related to the views and visibilities. A visibility graph analysis can be performed with the open-source software of DepthmapX, thus allowing for a computational framework to derive analyses of the visual integration of an architectural heritage based on the CAD drawings of its plan cut through at eye level [1].

Figure 1 illustrates the results. The spatial layout of each temple is paired with the plan as overlapped with the analyzed graph of visibility connectivity. The calculation of the visibility connectivity is based on the concept of a viewshed. A viewshed represents the area that can be directly viewed from a particular location in a spatial environment [2]. An analysis based on a viewshed is thus dependent on the physical geometrical configuration rather than the human behaviors. The visibility connectivity can be considered a graphical representation of accumulated analyses of all possible lines of sight from all possible points of view based on the unobstructed geometrical spatial layout at eye level [1]. As illustrated in Figure 1, the graphical presentation often utilizes color to denote the density of the lines of sight overlapping with the plan; in this colored grid map, the red regions are those that are more likely to be seen and can view more of the surrounding space.

The two temples have similar layouts that result from their traditional patterns. The space is enclosed by solid walls with multiple rows of columns. The center of the open courtyard and the open space in the front hall are therefore most easily visible when someone is in this area. The results of the visibility connectivity analysis confirm the above visual inspection. As the graphical analysis of visibility connectivity is a computational processing of all possible lines of sight from the available viewpoints, it is determined by the physical constraints of the site and falls short of addressing human preferences such as the decision of where to stop and where to look.

This analysis can thus only identify the place that is most frequently seen but falls short of identifying which specific scenes are most frequently viewed by visitors. This is because human behaviors are often directed by purpose, such as a ritual ceremony that is expected to be performed in the space. Therefore, the computational methods of Space Syntax cannot account for the identification of the canonical view of this particular type of architectural space.

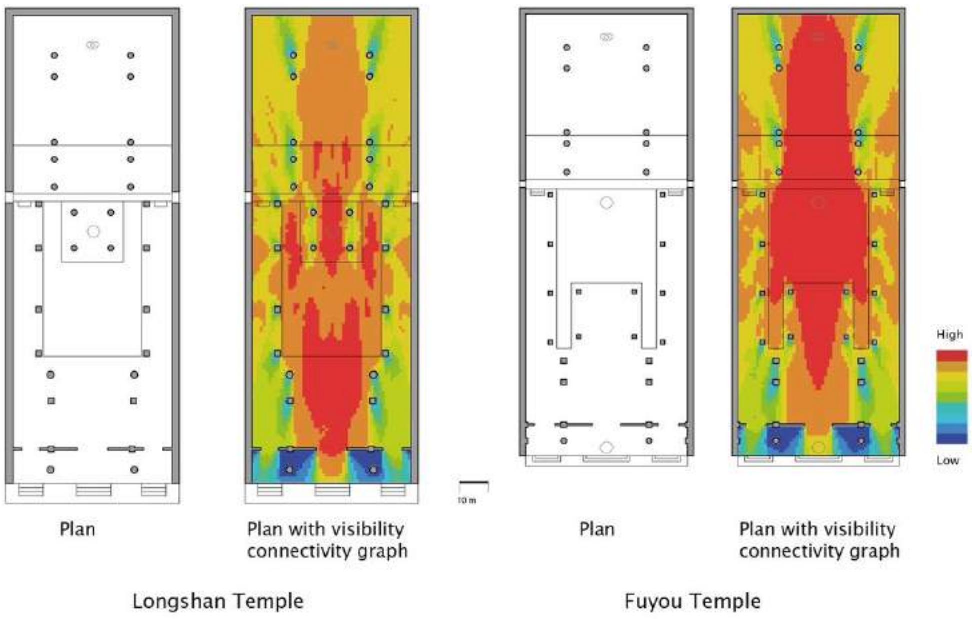


Figure 1: Plan and plan overlapped with visibility graph analysis of temples of Longshan and Fuyou.

2.4 Behavioral Mapping

Behavioral mapping is a research technique that is commonly used to study how a space is used by participants. It is based on an analysis of the records of tracking movements and behavioral patterns of the participants in the studied space [10]. For studies conducted to investigate human behavioral patterns in an architectural space, behavioral maps are often produced at sites with manually drawn symbols on floor plans that are printed on paper [12]. At the site, researchers pick one person who enters through the entrance, and use a symbol (e.g., a circle on the floor plan) to track the person's location at every 10 s. A circle with a line indicates the direction in which the person is looking, and an arrow means that the person is looking up in that direction, while a circle without a line or arrow indicates that the person is not viewing the space but is chatting with other people or is reading information.

In total, 62 people were recorded on two separate days for each temple. Each manually drawn tracking record sheet was redrawn on the same file of the vector-graphic computer program on different layers. This allowed for further analyses of the records based on different categories by turning the layers on and off. As illustrated in Figure 2(a) and Figure 3(a), in addition to recording where a person is standing and in what direction he or she is looking, we also denoted their appeared age. To exclude tourists and foreigners, we noted whether he or she offered burning incense with a bow, or put his or her palms together and bowed, as an indication of being in the temple for a religious purpose.

Figures 2(a) and 3(a) illustrate one example of the tracking records for each temple. Figures 2(b) and 3(b) and 2(c) and 3(c) are summaries of the overlapped behavioral maps of the temples of Longshan and Fuyou for people with and without a religious purpose, respectively. Among 62 tracking records, only 5 and 6 persons tracked at the Longshan and Fuyou temples were there without a religious purpose and did not perform a ritual ceremony. As persons with a religious purpose might be considered as believers and visit the temple more often, and thus are more likely to develop imprinted mental images of the spatial experience, the most frequently viewed scenes were thus based on an analysis of the overlapped behavioral mapping records of persons with a religious purpose.

As illustrated in Figure 4, three views (LS2, LS3, and LS1) that face toward the worshipped deity in the front and main halls and at the entrance of the temple are the most common views for the Longshan temple. In the case of the Fuyou temple, views gazing at the worshiped deity in the front and main halls are also the two most frequently encountered views (FY1 and FY2), while the third view (FY3) faces the incense burner.

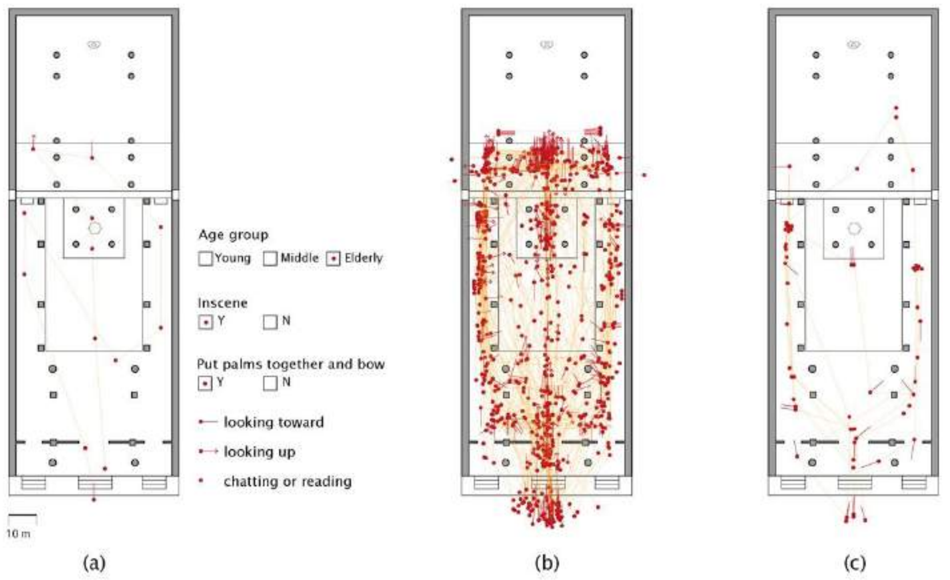


Figure 2: (a) Individual tracking record; (b) summarized behavioral mappings of believers; and (c) summarized behavioral mappings of nonbelievers for Longshan temple.

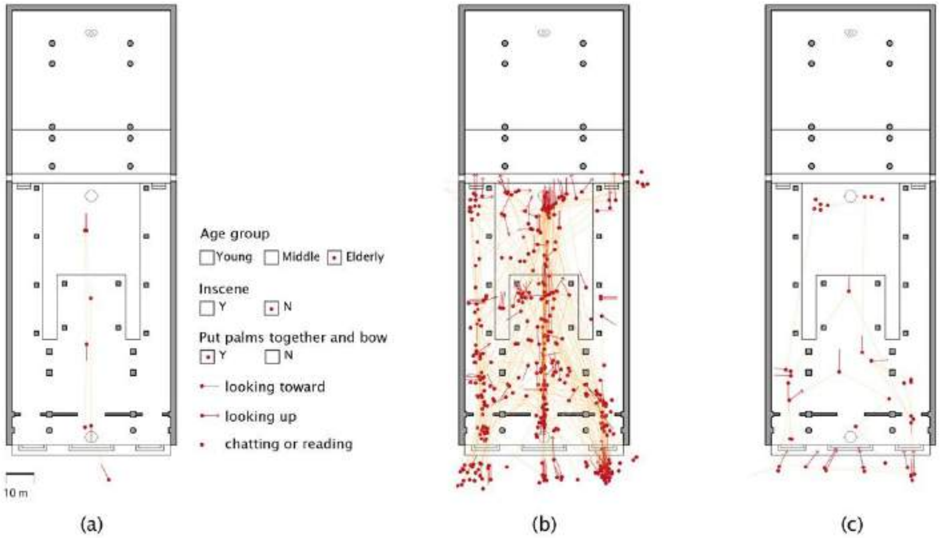


Figure 3: (a) Individual tracking record; (b) summarized behavioral mappings of believers; and (c) summarized behavioral mappings of nonbelievers for Fuyou temple.

3 PERCEPTUAL STUDIES

Two rounds of perceptual studies were conducted. In the first perceptual study, subjects were recruited through posters and oral invitations. This was considered a pilot study to investigate the perceptions of the general population. Seventeen volunteers were invited to participate in the study. They were mostly from the campus community and had been to the temples in Tamsui. Participants were invited to sit in a campus research lab. Temple images were presented on digital devices to allow viewers to make perceptual judgments.

There were three types of images. The first type of image included the most frequently viewed scenes based on the behavioral mappings. The second and third types were of significant architectural elements. Three views were close-range views of architectural details and assemblies, and another three views were distance views of structural configurations or decorations. These six views were acquired on site with reference to the published surveys of the two temples. Accordingly, they represent the photographs that are commonly used as supplements to the conceptual drawings in digital archiving. Figures 4 and 5 illustrate the two sets comprising nine images each for the temples of Longshan and Fuyou, respectively, as used for the perceptual studies. All images were taken by a Canon EOS Mark 5D III fitted with a Canon EF 50-mm lens that simulated the field of view of human vision.

The different sets of images were paired to display to participants. Before the trial, participants were prompted with a question such as, "Which image do you feel comes to your mind when you think of the space of Longshan temple?" Each pair was displayed in a sequence twice with the location swapped. The procedure was repeated two times for each set.

To recruit participants that more closely matched the persons we tracked for the study of behavioral mapping, a second round of the perceptual studies was conducted at the site of the Longshan and Fuyou temples. At each temple, 17 participants were recruited right after they performed the ritual ceremony and were about to exit. The same procedure used in the first perceptual study was carried out for the second and third perceptual studies conducted at the Longshan and Fuyou temples, respectively.

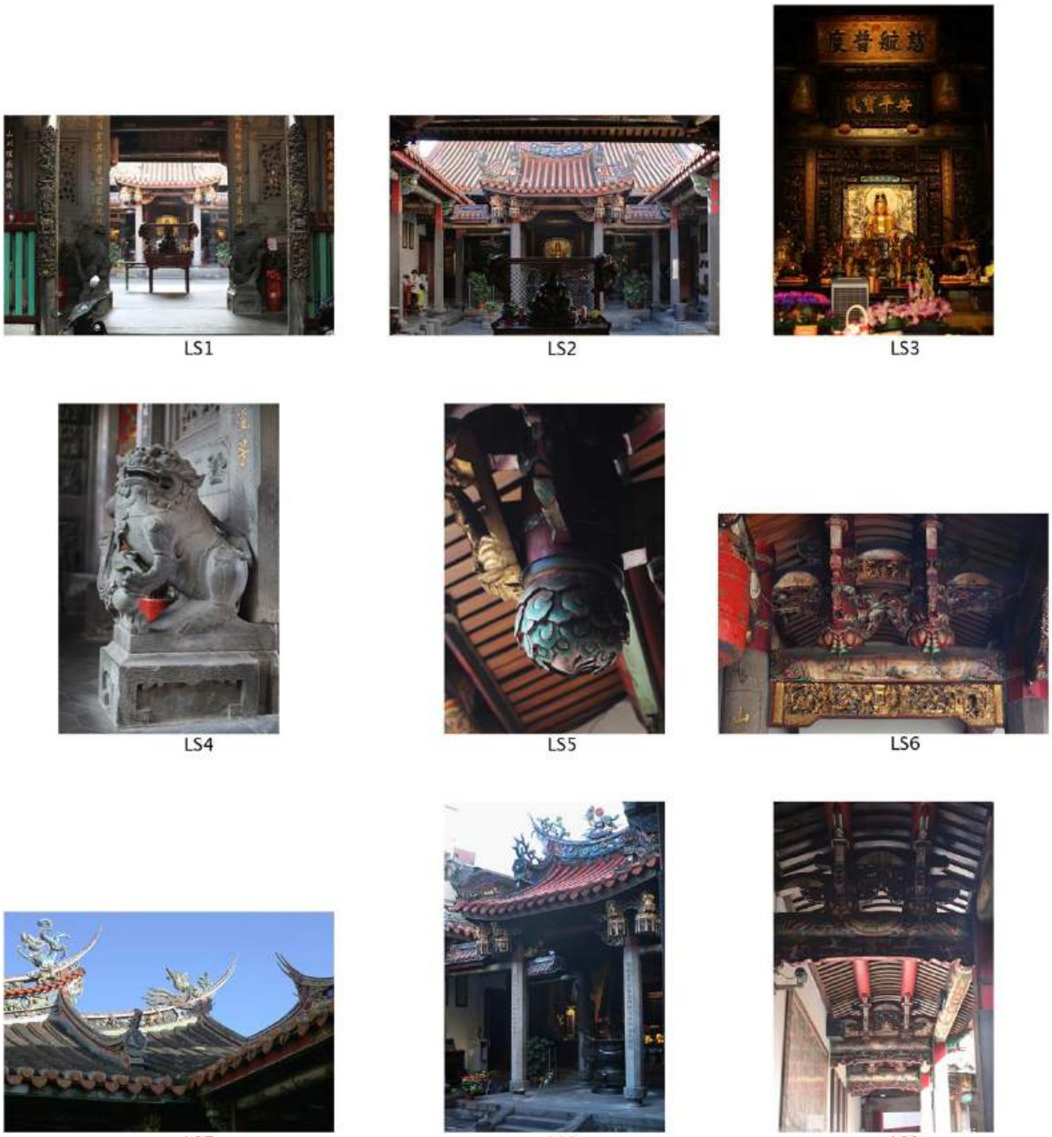
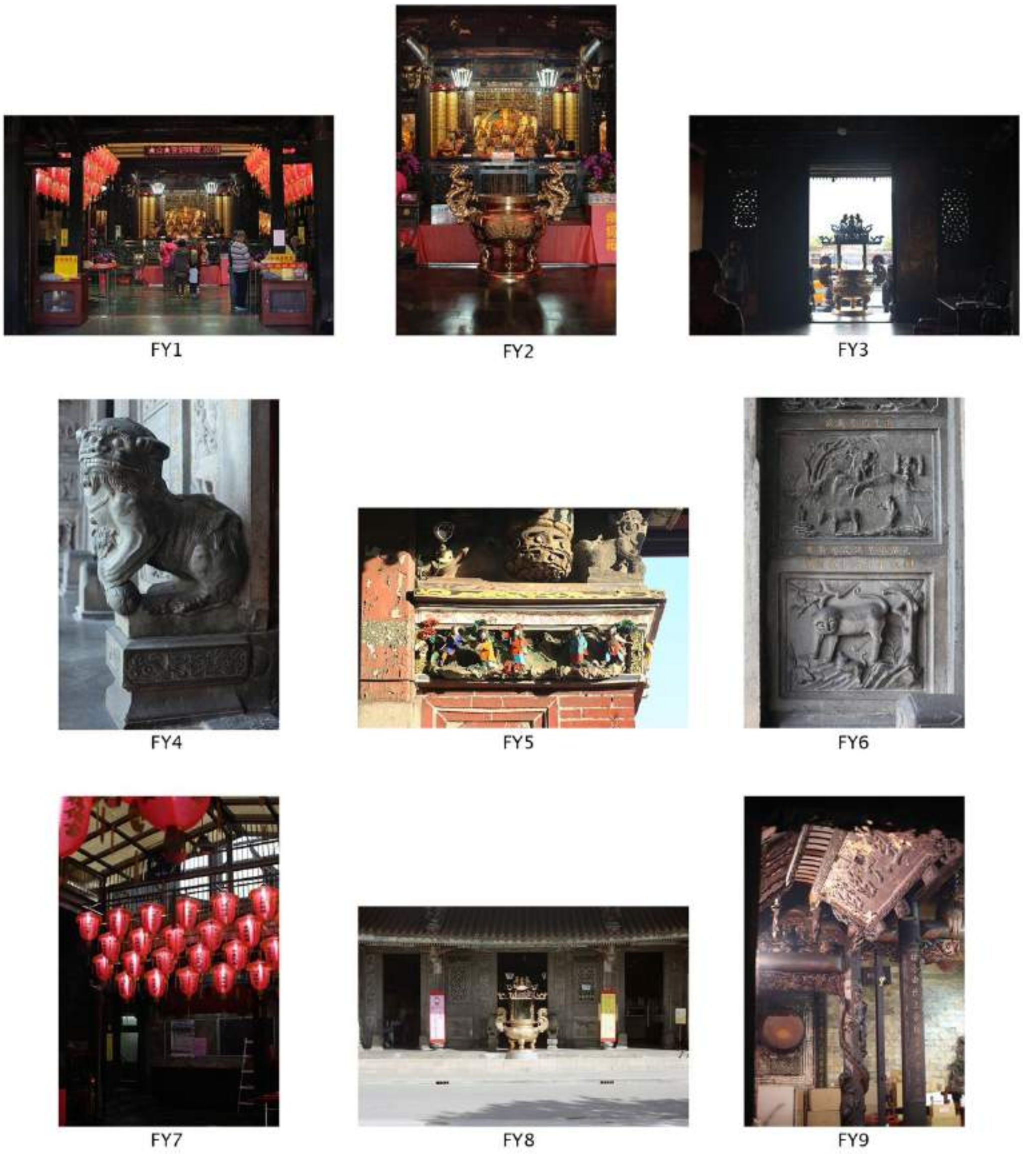


Figure 4: Images used for perceptual study of Longshan temple.

4 RESULTS AND DISCUSSION

Table 1 illustrates the results of the first perceptual study. Images were arranged based on the total numbers of preferred choices, and formed a preference scale. In the case of the Longshan temple, the two frequently viewed scenes upon entering the temple and the front hall (LS1 and LS2) occupied the first two choices, followed by the two distant views of the structural configurations or decorations (LS8 and LS9). The three close views that showed details were the least preferred (LS6, LS4, and LS5).



Fuyou Temple

Figure 5: Images used for perceptual study of Fuyou temple.

The third view of the group of most frequently viewed scenes was a view looking at the worshiped deity in a limited visual field (LS3). The fact that this view falls behind the two views of the spatial configuration on the preference scale suggests that the two hypotheses of frequency and maximal information can both influence the canonical view. Additionally, the hypothesis of frequency may be more effective than that of maximum information in our particular case study. Statistical analyses of the three types of views also confirmed that the group of the three most frequently viewed scenes was significantly preferred over the other two ($F_{2,32}$ = 94.588, $p < .0005$; post hoc analyses were significant between all three pairwise comparisons). In the case of the Fuyou temple, a similar trend can also be observed. The two interior views that were based on the most frequently viewed scenes were the most preferred views (FY1 and FY2). However, the third view of the most frequently viewed scene was listed fifth in the order of preference (FY3). This can be attributed to the fact that this view faced outside the temple and contained limited visual information of the space.

Preference Scale for Perceptual Study Conducted at Campus

Longshan Temple									
Scene	**LS1**	**LS2**	**LS8**	**LS9**	**LS3**	**LS7**	**LS6**	**LS4**	**LS5**
Numbers of Preferred	236	229	170	165	145	104	73	54	48
Percentage of Preferences (%)	19.3	18.7	13.9	13.5	11.8	8.5	6.0	4.4	3.9
Fuyou Temple									
Scene	**FY1**	**FY2**	**FY8**	**FY9**	**FY3**	**FY7**	**FY5**	**FY4**	**FY6**
Numbers of Preferred	239	203	170	169	157	121	74	60	31
Percentage of Preferences (%)	19.5	16.6	13.9	13.8	12.8	9.9	6.0	4.9	2.5

Table 1: Preference scale for temples of Longshan and Fuyou for perceptual study conducted at campus.

Table 2 and 3, meanwhile, illustrate the preference scales for the scenes of the two temples when the participants undertook perceptual studies at the Longshan and Fuyou temples, respectively. The results of the two studies agree in general with the first perceptual study. The group of most frequently viewed scenes was preferred over the distant views of architectural spatial configurations and was followed by the close views of the architectural details. However, the most preferred views varied from the three perceptual studies.

For the study conducted at the Longshan temple, the most frequently viewed scenes were the three most preferred for the Longshan temple, but for the Fuyou temple, the scene revealing the spatial configuration of the ceiling of the main hall (FY9) moved to the first position, pushing the most frequently viewed scenes one spot downward in the order. For the perceptual study conducted at Fuyou temple, the interior views of Longshan temple with visual attention toward the worshiped deity (LS2 and LS3) were the first two preferred, followed by that with spatial information along with traditional craftmanship (LS8), consequently pushing that most preferred in the study conducted on the campus (LS1) to fourth position. Meanwhile, the most frequently viewed scenes at the Fuyou temple occupied the first three positions (FY1, FY2, and FY3), followed by the distant views (FY7, FY8, and FY9), and then the group of close-range views of the architectural details (FY4, FY6, and FY5).

Because the hypothesis of frequency suggests that the canonical view of a subject is a mental image imprinted because it has been seen so many times in one's life, we believe that the preference scale of the particular space should be based on the participants who have visited that particular space more often. In other words, the preference scales of the canonical view of the Longshan temple should be more reliable for a study conducted at that temple, while the preference scale of the canonical view of the Fuyou Temple should be more reliable for a study conducted at that temple. The results demonstrated in Table 2 and 3 confirm this speculation. The preference scales of the canonical view of the Longshan temple conducted at that temple and the preference scale of the canonical view of Fuyou temple conducted at that temple closely match the expected order of the hypothesis (LS3, LS2, LS1, LS7, LS8, LS4, LS9, LS6, and LS5; FY1, FY2, FY3, FY7, FY8, FY9, FY4, FY6, and FY5).

Another interesting observation of the preference scale for the Fuyou temple conducted at the Longshan temple is that scene FY9 finished first among the participants who performed the perceptual study at the site of the Longshan temple. One possible explanation for this unexpected result might be the current states of preservation of the two temples.

Both LS2 and FY1, and LS3 and FY2, are scenes that believers most often view when performing ritual ceremonies at the temple. In particular, for LS2 and FY1, the scenes viewed upon entering the front hall, looking toward the worshiped deity through the courtyard, present differently owing to the preservation conditions of the two temples. This scene at the Fuyou temple was dramatically changed from its commonly appreciated similar scenes owing to remodeling. An additional roof covered the courtyard and unfortunately induced more artificial lighting to compensate for the reduced daylight. Thus, this scene (FY1) was quite different from its original design of years ago.

The statistical analysis of the difference between the preferred choices of scene LS2 between the two groups of 17 participants performing a perceptual study at the temples of Longshan and Fuyou is insignificant. However, the analysis is significant for scene FY1. This might support the above speculation ($F_{1,32} = 0.944$, $p > .05$ for LS2; $F_{1,32} = 6.934$, $p < .05$ for FY1). This suggests that the canonical view of an architectural heritage might also be influenced by its preservation condition when demonstrating a commonly appreciated visual appearance of the historical architectural space.

Preference Scale for Perceptual Study Conducted at Longshan Temple

Longshan Temple									
Scene	**LS3**	**LS2**	**LS1**	**LS7**	**LS8**	**LS4**	**LS9**	**LS6**	**LS5**
Numbers of Preferred	195	191	156	149	126	122	117	104	64
Percentage of Preferences (%)	15.9	15.6	12.7	12.2	10.3	10.0	9.6	8.5	5.2
Fuyou Temple									
Scene	**FY9**	**FY2**	**FY1**	**FY3**	**FY5**	**FY8**	**FY4**	**FY7**	**FY6**
Numbers of Preferred	177	160	156	147	146	136	114	103	85
Percentage of Preferences (%)	14.5	13.1	12.7	12.0	11.9	11.1	9.3	8.4	6.9

Table 2: Preference scale for temples of Longshan and Fuyou for perceptual study conducted at Longshan Temple.

Preference Scale for Perceptual Study Conducted at Fuyou Temple

Longshan Temple									
Scene	**LS2**	**LS3**	**LS8**	**LS1**	**LS7**	**LS9**	**LS6**	**LS4**	**LS5**
Numbers of Preferred	208	196	189	174	133	115	112	59	38
Percentage of Preferences (%)	17.0	16.0	15.4	14.2	10.9	9.4	9.2	4.8	3.1
Fuyou Temple									
Scene	**FY1**	**FY2**	**FY3**	**FY7**	**FY8**	**FY9**	**FY4**	**FY6**	**FY5**
Numbers of Preferred	214	192	170	161	141	120	83	72	71
Percentage of Preferences (%)	17.5	15.7	13.9	13.2	11.5	9.8	6.8	5.9	5.8

Table 3: Preference scale for temples of Longshan and Fuyou for perceptual study conducted at Fuyou Temple.

5 CONCLUSIONS

The fact that three different views and two different views are the most preferred canonical views of Longshan and Fuyou temple, respectively, for the three perceptual studies conducted at different locations implies that the most representative canonical view can be difficult to identify. Many factors influence how an historical architectural scene impresses us and therefore imprints on our memory. These factors include how often we have seen it, how it presents to us at a particular time with particular lighting, and how the scene is preserved with the craftmanship with which we are familiar and appreciate. As this study only use limited scenes for perceptual study, the result can only indicate a general method to identify the canonical view of an architectural heritage.

In our study, the results of the perceptual studies indicated that views from the more frequent perspectives were selected compared to the views of architectural details when people were asked to recall the architectural space. This result is in agreement with the hypothesis that the most frequently viewed scene can be considered to be the canonical view of the space. However, the results also show that frequent views that include more spatial information are preferred compared to those with a limited visual focus. This can be attributed to the other canonical view based on the hypothesis of maximal information. Therefore, we conclude that the most frequently viewed scene with a wide visual field of the interior space is the preferred representative image stored in our memory for that particular space.

Studies also showed that the most frequently viewed scene can be more precisely identified by the behavioral mapping method. Given that the most frequently viewed scene involves human behavioral patterns, visibility analyses conducted using DepthmapX were based solely on the physical configuration and could only identify the most frequently viewed spot. Although the identified spot cannot provide the most frequently viewed scene associated with the stored perception of the architectural space, it does imply that there is an ideal location to capture a panoramic view or 360° image to document the maximal amount of visual information in a single image. As illustrated in Figures 6 and 7, both panoramic and 360° spherical images can be used in postprocessing to restore all available sight of viewed scenes from that particular location.

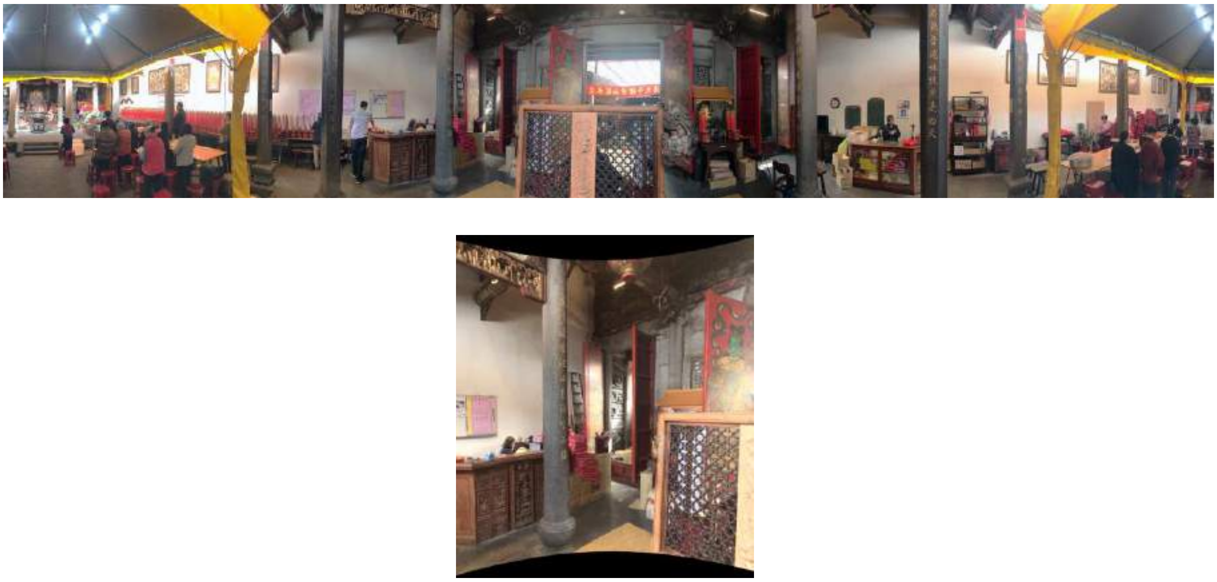


Figure 6: Panoramic image captured at location identified by Space Syntax, and possible viewed scenes restored from image.

An HDR image can also be generated with photos captured using circular fisheye lenses, allowing two fisheye HDR images to be stitched into one 360° image for restoring all possible views from the location where the fisheye photos were taken [9]. As a result, related technologies of HDR photography provide a practical solution to archiving the perceptual experience of architectural spaces of cultural heritage.

Figure 7: Maximal visual information recorded via 360° image based on point of view identified by Space Syntax, and possible viewed scene restored from 360° image.

This study thus proposed a computational framework that uses methods of behavioral mapping to identify the most frequently viewed scenes in a space, and Space Syntax to identify the locations with the highest visibility connectivity. These scenes can then be recorded with HDR photography using a 50-mm lens and a fisheye lens, respectively. For the fisheye images, the framework serves as a database of visual information from which to restore the viewing scenes for reference. The 50-mm image simulates the visual perception of the architectural scenes and serves as an archive of the perceptual experience of the architectural space that is most representative of the images in a person's memory.

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Nan-Ching Tai, http://orcid.org/0000-0001-6656-3285
Li-Wen Sung, http://orcid.org/0000-0003-0028-1597

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