Journal of Cultural Heritage 39 (2019) 202–211

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

Original article

Generating a virtual tour for the preservation of the (in)tangible cultural heritage of Tampines Chinese Temple in Singapore

Osten Bang Ping Mah [b], Yingwei Yan [a], Jonathan Song Yi Tan [b], Yi-Xuan Tan [b], Geralyn Qi Ying Tay [b], Da Jian Chiam [b], Yi-Chen Wang [b], Kenneth Dean [a], Chen-Chieh Feng [b,*]

[a] Department of Chinese Studies, National University of Singapore, AS8, 10, Kent Ridge Crescent, 119260 Singapore, Singapore
[b] Department of Geography, National University of Singapore, AS2, 1 Arts Link, 117570 Singapore, Singapore

ARTICLE INFO

Article history:
Received 19 October 2018
Accepted 8 April 2019
Available online 7 May 2019

Keywords:
Virtual tour
Tangible heritage
Intangible heritage
Geotagging
Image processing

ABSTRACT

There is a growing use of digital and visualisation technologies in the documentation and preservation of cultural heritage sites. Using the Tampines Chinese Temple in Singapore as a case study, this paper presents a detailed methodological framework to create virtual tours for the preservation of both the physical built environment and intangible historical and sociocultural elements within the space of cultural heritage sites. Tangible data used in the creation of the virtual tour produced for the temple comprise spherical images collected via a 360° camera and two-dimensional (2D) high-resolution images obtained via a digital single-lens reflex camera. The tour also showcases intangible aspects of the temples cultural heritage, derived from references made to multiple sources, namely interviews with personnel involved in the management of heritage sites (e.g. the temple secretary) as well as historical archives (e.g. National Archives of Singapore and publications produced by the temple). In so doing, this paper promotes the importance of incorporating intangible elements of cultural heritage sites into a unified interface. This method is advantageous as the relatively low pricing of the chosen software, and the use of a 360° camera and digital single-lens reflex camera enhances accessibility for heritage practitioners and facilitate future applications.

1. Introduction

While numerous studies have discussed heritage as contested [1–3] or as a value-laden concept [4,5], recent works have espoused the notion of heritage as a process [6–8]. Heritage as a process encompasses heritage interpretation and heritage management. The former relates to the identification of places as heritage and the reasons for perceiving them as such [9] while the latter concerns the safeguarding of heritage places [10]. In terms of heritage management, there is a growing use of digital and visualisation technologies to document cultural heritages [11]. Many novel approaches and strategies have been proposed, including (but not limited to) photogrammetry and laser scanning techniques [12], image-based 3D reconstructions [13,14] and Virtual Reality (VR) [15]. Many of these approaches involve introducing new means of data acquisition and processing systems, the collection of data using sophisticated equipment (such as laser scanners and GPS), and the synergizing of a myriad of technologies across disciplines to boost the effectiveness of heritage conservation strategies [14].

This study intersects with the digital humanities realm as we utilise digital technologies in the form of virtual tour software to document (and archive) the cultural information of a heritage site. However, prior efforts involving the use of such technologies have disproportionately focused on documenting the tangible structures of heritage sites. To address this imbalance, we propose a more holistic approach that documents the tangible structures in tandem with intangible aspects of the cultural heritage of these sites. Considering the intangible aspects is aligned with Champions ([16]: emphasis added) notion of virtual heritage environment, which "display[s] content in new and more experientially appropriate ways, bridging disparate collections and remote sites with the intangible heritage of the original shareholders (such as oral history, mythology, and other cultural beliefs and traditions) beyond the physical constraints of the real world".

This paper is structured as follows. In the following section, we review the use of digital and visualisation technologies for heritage

* Corresponding author.
E-mail address: geofcc@nus.edu.sg (C.-C. Feng).

https://doi.org/10.1016/j.culher.2019.04.004
1296-2074/

management, highlighting a tendency to focus on documenting the physical built environment. Section 3 outlines our research aims. Section 4, which we have subdivided into five sections, discusses the materials and methodology deployed in this study. Following a brief introduction to our case study, we justify the chosen software before explaining the three main components of our workflow:

- data collection;
- data preprocessing; and;
- data processing.

Section 5 presents our virtual tour (VT) output. Section 6 discusses the results, including a list of suggestions on enhancing our proposed method for future work to consider, and Section 7 concludes.

2. (In)tangible cultural heritage

Extant literature on the management of cultural heritage sites are based predominantly in the architectural discipline. Techniques ranging from laser scanning, 3D point clouds to digital photogrammetry represented the more prominent methods utilised in the documentation of tangible cultural heritage. For instance, Yastikli [17] utilised terrestrial laser scanning technology that produced very dense 3D points on an object surface to generate a 3D model for the Dolmabahce Palace in Turkey. The focus on architectural elements is also evident from Murphy et al. [18] implementation of a relatively newer approach of Historic Building Information Modelling to conserve the historical artefacts and architecture in Europe. While most works focused on representing architectural heritage information through 3D modelling, Colucci et al. [19] have added a new dimension by incorporating description of damage mechanisms into the 3D geometric features of cultural heritage buildings. Specifically, focusing on the Italian context, their work sought to preserve information about architectural heritage in the aftermath of a disaster event. Adopting a similar focus on natural (and anthropogenic) hazards, Agapiou et al. [20] utilised remote sensing data and conducted Geographic Information System (GIS) analysis to create a hazard map indicating levels of risk for the monuments located in the Paphos area in Cyprus. Discussion on the physical built environment is also evident from Apollonio et al. [21] application of the AutoCAD modelling tool to preserve architectural information of cultural heritage sites. Tangible aspects also include building materials [22], the constructive typologies [23], and the state of conservation of historical buildings [23,24]. Despite the various developments in the (architectural) documentation of cultural heritage sites, there is a disproportionate emphasis on preserving the tangible aspects of cultural heritage, to the extent of obscuring the documentation of intangible cultural heritage.

The focus on quantifying the tangible aspects of cultural heritage sites has not only downplayed and neglected the intangible aspects which can offer the subjective dimension of cultural meanings to the cultural heritage sites but has also “exclude[d] the user as a multi-dimensional human being” ([25] cited in [26]: 1). Having said that, several researchers examining the use of digital and visualisation technologies in heritage documentation have recently highlighted the importance of considering the intangible elements of cultural heritage sites. For instance, in their documentation of Chinese Hakka culture in Chinas Fujian province, [27]: 178) integrated “cultural thematic information and maps of Hakka” into the 3D geographic information service system. However, methodological details explaining their integration of these intangible aspects are lacking, which our paper will be addressing. Furthermore, the terrestrial laser scanning techniques deployed are inaccessible with cost and technical expertise as barriers for users. Moreover, Napolitano et al. [28] research on a conservation site in the Princeton University campus in the United States also attempts to complement the physical built environment with intangible information. This information, however, is related to the buildings condition and past, present and future interventions to address any structural deficiencies. Building on Napolitano et al. attempt, we argue that intangible aspects of cultural heritage sites can go beyond information pertaining to the built structure, and also include the historical and socio-cultural knowledge of artefacts in the building.

Previous attempts to assimilate both tangible and intangible aspects of cultural heritage sites into a unified interface to date have been scant, and the studies that did so utilised a variety of different methodological approaches and visualisation methods across different scales. Bruno et al. [29] proposed a methodology to preserve archaeological collection by developing a virtual exhibition system, which couples 3D models of tangible artefacts overlaid over an archeological map with a virtual museum comprising of audio samples, picture galleries, introductory screens and movies of the artefact. Their virtual exhibition was however only limited to the preservation of miniscule artefacts and does not encompass the preservation of whole places. Google Arts and Culture (https://artsandculture.google.com/) is a similar initiative, albeit preserving heritage entities at a much larger scale. It is an online platform where exhibits of museums, galleries and institutions worldwide are made accessible to the public [30]. First launched in 2011, the service has expanded since then and provides a broad range of features such as virtual reality, interactive search, virtual tours, translation services and guided tours (ibid.). Google however keeps their source code proprietary and privatised, which prevents others from adopting their software interfaces. In addition, the tangible and intangible aspects on their website are kept disparate in terms of virtual tours [31] and interactive storyboards [32], and the former does not contain any form of semantic information about the exhibits depicted in the tour. Finally, Richards-Rissetto et al. [33] combined 3D GIS with gesture-based Kinetic technology to engage the public in ancient Maya archaeology. Their system not only allows users to navigate a virtual reality landscape but also provides interactive pedagogical devices such as (interactive) narration, videos, storylines and hieroglyphic texts to facilitate cultural heritage knowledge to the public. However, their study necessitates the use of sophisticated hardware and demands considerable technical expertise for execution, which compromises on the accessibility for heritage practitioners. In general, many methodological details (e.g., data collection strategy and steps of the processing and inclusion of relevant data) are omitted from these previous attempts, which focused more on presenting the general steps and outputs.

3. Research aims

Using Tampines Chinese Temple in Singapore as a case study of cultural heritage sites, this study aims to offer a methodological framework for the creation of a VT to preserve both its built environment and intangible socio-cultural elements. Incorporating historical and socio-cultural knowledge of the temple into the VT is also aligned with the Singapores state recent recognition of the importance of the intangible, as evident from its recent nomination of hawker culture for inscription into the United Nations Educational, Scientific and Cultural Organisation List of the Intangible Cultural Heritage of Humanity [34]. Leveraging on both spherical images collected using a 360° camera and 2D high-resolution images obtained from a Digital Single-Lens Reflex (DSLR) camera, we produced a semantically-enriched VT of the temple hosted on Cupix software. With this VT, users can now acquire essential historical and cultural knowledge related to the temple in

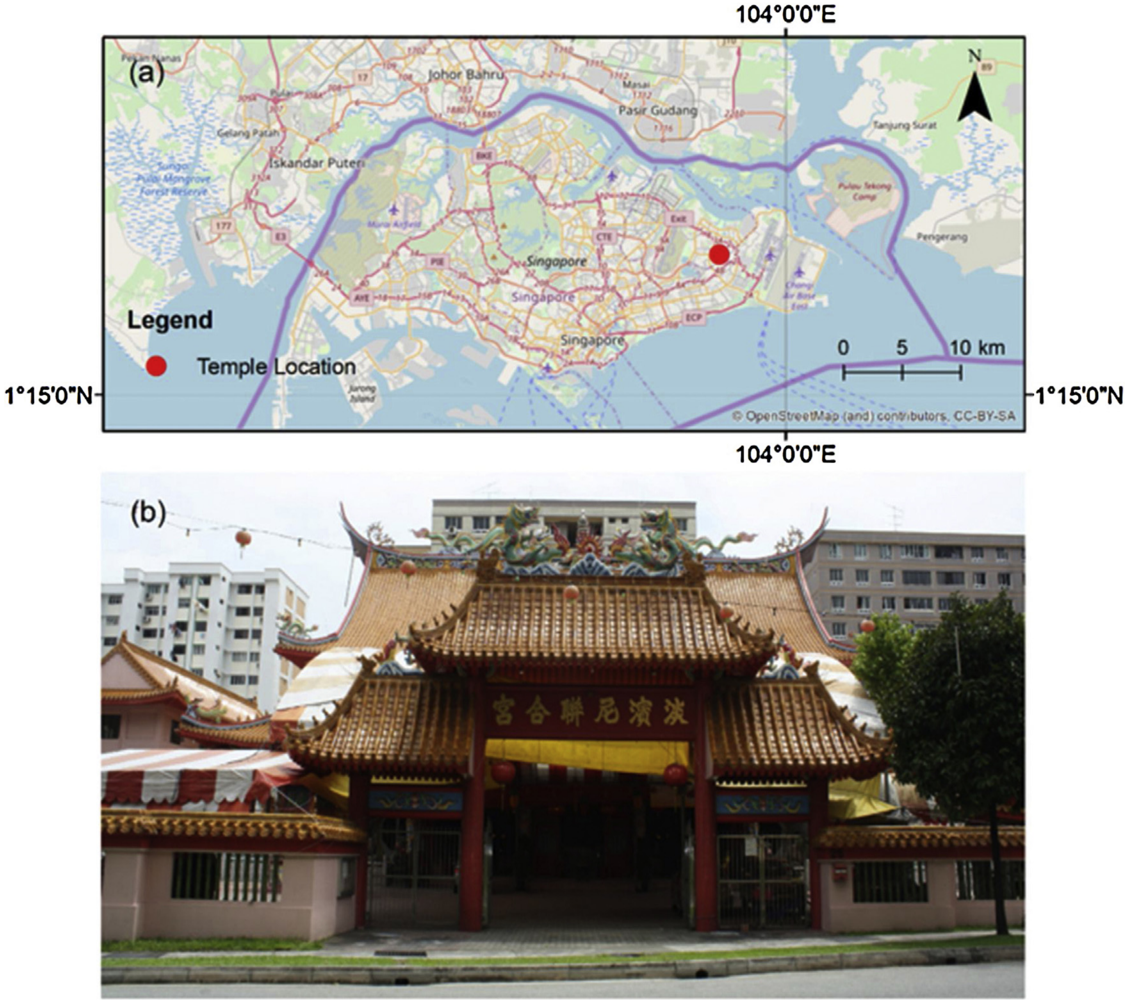

Fig. 1. a: Map showing the location of the Tampines Chinese Temple (background map is the OpenStreetMap); b: Photo showing the main gate of the Tampines Chinese Temple.

an immersive environment without having to laboriously access numerous secondary data sources on their own. In addition to facilitating understanding and preservation of the historic fabric and cultural aspects of the temple, this study also serves as a foundation for other cultural heritage building preservation projects to contextualise and replicate.

4. Materials and methods

4.1. Study area

Constructed in 1992, the Tampines Chinese Temple (Fig. 1) is a united temple formed by the amalgamation of 12 constituent temples. The temple, with a total floor area of 37,000 square feet, is designed using an open layout concept [35].

Fig. 2 illustrates the layout of the temple. The outdoor courtyard comprises an open space where the two temple censers are located, and ritual performances are conducted. Chinese murals are inscribed on the walls and the supporting beams of the temple. The indoor area can be divided into three sections:

- the top left section of the indoor area is mainly used for the storage of temple procession and ritual paraphernalia;
- the middle section is the main worship area where the deities are situated;
- the top right section is where the temples main office and the store (where devotees can purchase items such as joss sticks for praying) are located.

An offering table is placed in front of each deity. Every table has a censer to allow devotees to place their joss sticks after praying. A mini-bell, which would be rung by devotees after praying, is installed adjacent to each offering table. Conical shape towers are also placed to allow for the placement of prosperity lamps which are believed to bring good fortune and health to the devotee.

Moreover, the National Heritage Board (NHB) in Singapore attached heritage significance to the Tampines Chinese Temple. This attachment is evident from its listing of the temple as a heritage site on the Tampines Heritage Trail National Heritage Board [36], which presents the cultural heritage of the Tampines district (see Appendix A). Our VT output has practical significance as it can serve as a pedagogical tool for the dissemination of historical knowledge to the next generation [37]. There is a pressing need for this dissemination due to the temples uncertain long-term future: the temple is currently on a 30-year lease with no guarantee of renewal.

4.2. Software selection and workflow

Three software packages were considered for generating the VT – Cupix (https://www.cupix.com), Walkabout Worlds (http://www.walkaboutworlds.com) and Paneek (https://www.paneek.net). A scrutiny of these software packages

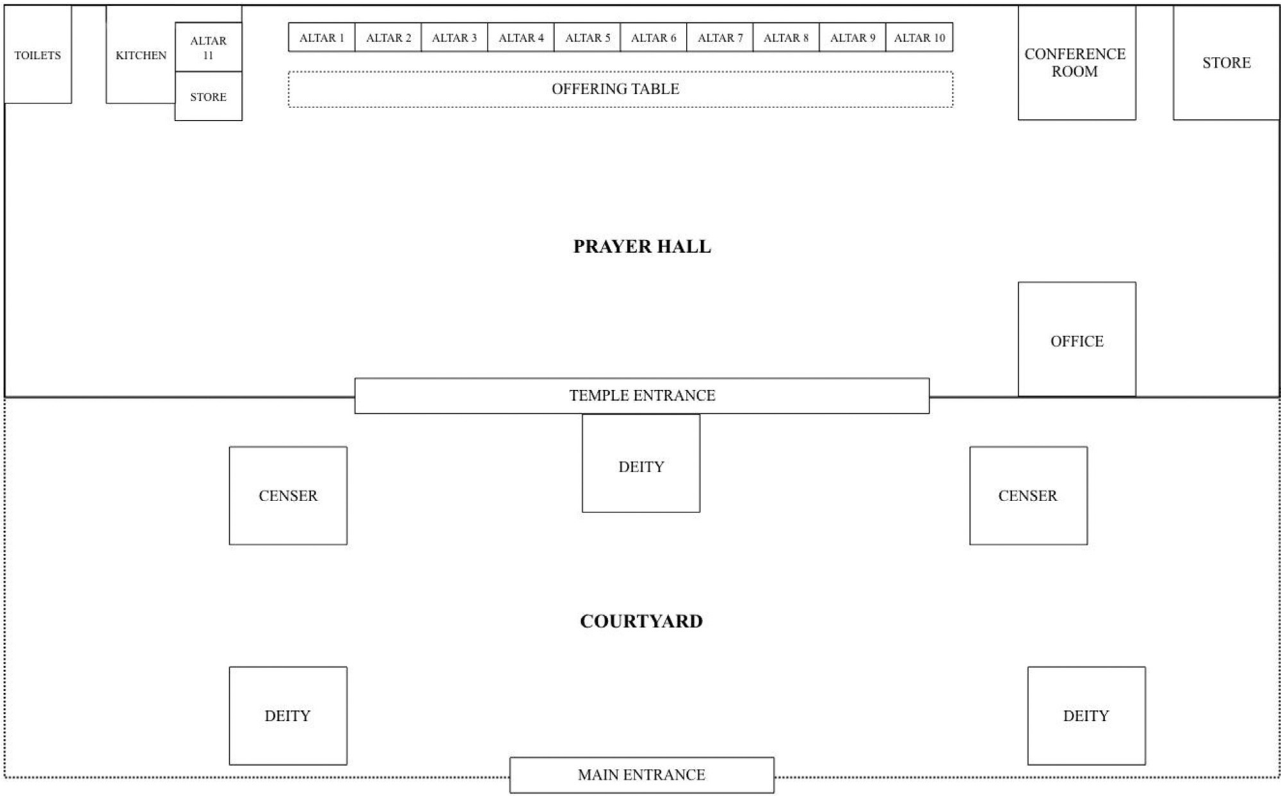

Fig. 2. Layout of Tampines Chinese Temple.

Table 1
Comparison of the three software packages for building the VT.

	Ability to geo-tag information	Ability to navigate freely within a VT environment	Minimal human intervention in image processing
Cupix	√	√	√
Walkabout Worlds		√	
Paneek	√		√

revealed that Walkabout Worlds and Paneek were unable to address certain requirements (Table 1). First, creating a VT on Walkabout Worlds demands intensive human intervention as every 3D surface in the tour must be generated from the data collection points, whereas in contrast, Cupix can create the entire VT automatically. Second, Paneek does not have the immersive VT capability, as it only allows its users to view the environment from a fixed position in the space. Therefore, we settled on using Cupix to create our VT because it allows for geotagging information (texts, web images and audio clips) to specific spots and free navigation within a VT and requires minimal human intervention in image processing. Additionally, there is also transferability of the VT in terms of its potential to be incorporated into Google Street View, thereby increasing its overall usability, value, and accessibility to a wider community.

Based on the features of Cupix, we formulated a methodology to develop the VT which encompasses three main steps (Fig. 3): data collection (tangible and intangible data), data preprocessing and data processing.

4.3. Data collection

This section is divided into two sub-sections, which explain the procedures adopted in our collection of both tangible and intangible data.

4.3.1. Tangible data

The tangible data were collected through an on-site survey using a 360° camera and a DSLR camera. The 360° camera was used to capture spherical images of the temple (Fig. 4a). The raw spherical images were subsequently processed into panoramic images (Fig. 4b). It was also observed that the level of detail for distant objects was diminished. Specifically, the 360° images of the murals located near the ceiling of the inner sanctum of the temple were of low image resolution. Hence, the DSLR camera was used to capture high-resolution 2D images of the murals. As shown in Fig. 5, these 2D images were superimposed onto the panoramic images to address the low visibility of the murals.

Specifically, images were captured from data collection positions (viewpoints) denoted using grey points in Fig. 6. To ensure a level view and consistent angle applied to all the spherical images, a stabilizer with a built-in bubble level was used during the collection of 360° images. The images covered the entire spatial view of the temple. It was challenging to decide the number of data collection points and the appropriate locations of the points. We resolved this challenge by applying a trial-and-error method for the improvement of the data collection. For enclosed spaces or key areas of the temple (e.g. blind spots around an altar), viewpoints were deliberately selected and arranged using triangulation (e.g. the three grey points within the dash-line triangle displayed in Fig. 6) to ensure maximum coverage of the temple.

Although the spherical images were of higher resolution, they did not have the same level of overlap or ease of collection as compared to spherical videos. Thus, a mixed-data method was adopted, which involved recording spherical videos encompassing the entire floor area of the temple to complement the spherical images in the VT,

4.3.2. Intangible data

Intangible data, relating to the cultural and historical information of the temple, were mainly collected through semi-structured

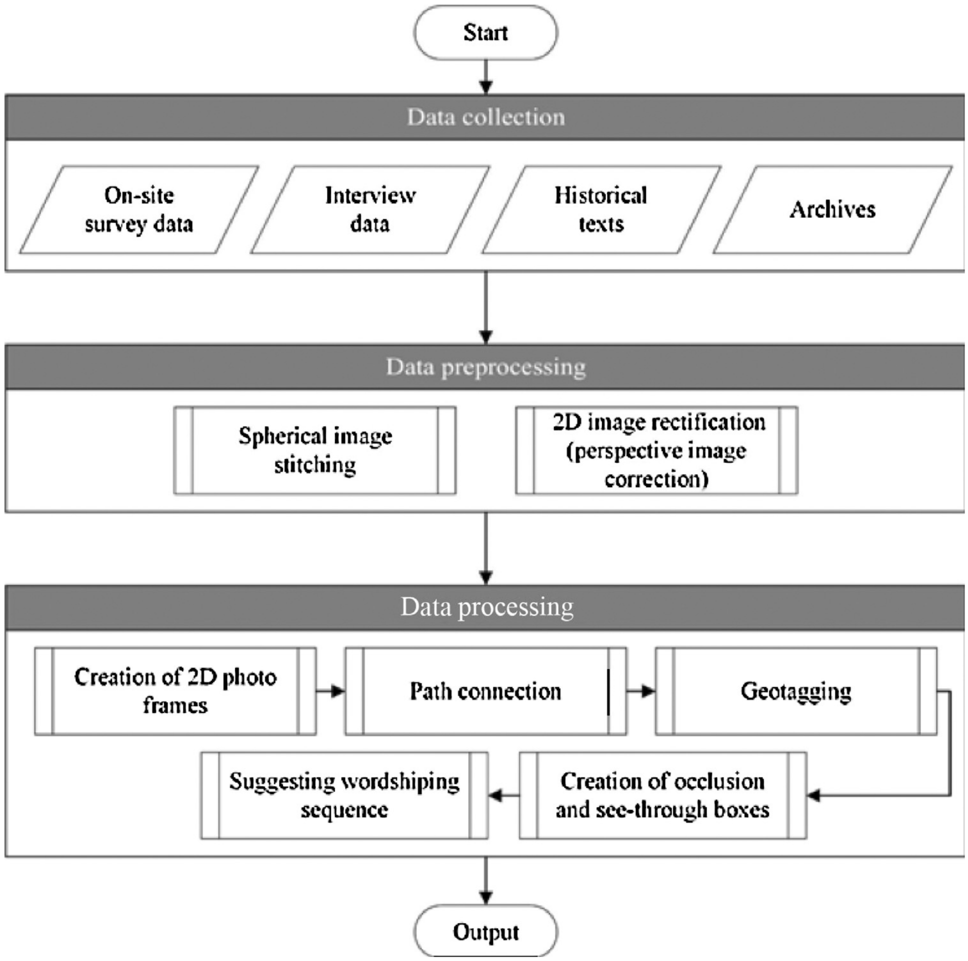

Fig. 3. Workflow outlining the creation of the VT.

interviews with the temple secretary. Through these interviews, the following historical information were collated:

- the oldest subsidiary temple (i.e. Shun Xing Gu Miao dating back 167 years ago) of Tampines Chinese Temple;
- original locations of the subsidiary temples (i.e. all subsidiary temples were initially situated in Tampines at the Eastern Singapore, except for Ji Yang Tang as it was originally located in Amoy Street at Southern Singapore);
- significance or religious hierarchy of the deities (e.g. the Jade Emperor is the main God of Taoists, and hence occupies the first prayer spot in the worshipping sequence suggested by the temple);
- ritual practices (e.g. the number of joss sticks needed for praying);
- the significance of various artefacts within the temple (e.g. the lanterns placed at the top section of the interior of the temple signify devotees wishes for good fortune and prosperity).

Textual information collated and compiled from the temples publications [38,39,40] complemented the information obtained from the interviews. This textual information comprised the broader urban planning contexts that shaped the formation of the Tampines Chinese Temple, the history of each subsidiary temple, and the stories associated with the deities.

Furthermore, historical photographs of the subsidiary temples were retrieved from the National Archives of Singapore (http://www.nas.gov.sg/archivesonline) to offer visual illustrations of the temples prior to the merger of the Tampines Chinese Temple. References were also made to information and stories featured on the Singapore Memory Project (https://www.singaporememory.sg), an initiative spearheaded by the National Library Board, to gain an understanding of the temples significance as a cultural heritage site in Singapore.

4.4. Data preprocessing

As per the requirements of the Cupix software, a total of 145 raw spherical images (Fig. 4a) collected using the 360° camera were first converted into panoramic images using a ratio of 2:1 (Fig. 4b). This step was achieved through the use of the Samsung® ActionDirector tool, before the panoramic images were stitched together. In addition, some images captured using the DSLR camera during the on-site survey were out of alignment (i.e. appeared tilted). Perspective rectifications were performed to remedy the angles of the images using the *Perspective Image Correction* tool. These preprocessed data were used as the input to create a preliminary VT in Cupix. In the data collection and preprocessing steps, the indoor and courtyard were grouped into respective sections and processed separately. To create an integrated VT, prior to the subsequent data processing, the indoor and courtyard sections were merged by matching common regions such as doors and walls.

4.5. Data processing

The data processing stage involves five steps, including the creation of 2D photo frames, path connection, geotagging, the creation

Fig. 4. a: A raw spherical image captured by the 360° camera; b: a panoramic image.

Fig. 5. A mural near the ceiling of the inner sanctum of the temple with a photo frame created to superimpose the high-resolution DSLR image of the mural onto the background.

of occlusion and see-through boxes, and the incorporation of the suggested worshiping sequence (Fig. 3).

First, photo frames were inserted to place the 2D images of the murals near the ceiling captured using the DSLR camera (Fig. 5). Second, to allow users to navigate freely within the indoor environment of the temple, the viewpoints must be connected (Fig. 6) so that the connections would lead to logical real-world user movements. Instances of unrealistic user movements such as travelling through the altars or walls were avoided. Additionally, viewpoints with spherical images that were of a low quality or

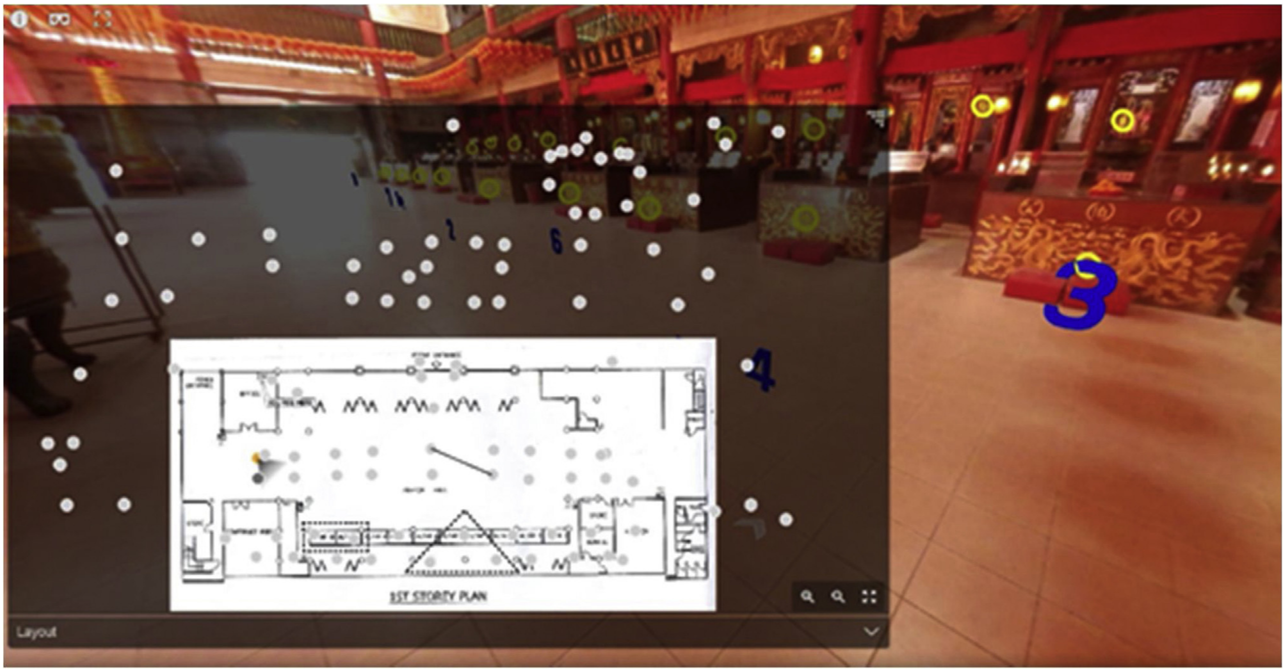

Fig. 6. Floorplan of the temple illustrating the data collection positions (the grey points) in both the indoor area of the temple – area covered by the floorplan, and the courtyard of the temple – area not covered by the floorplan. The orange point and the radar indicate the location of the user, which is one of the viewpoints, and the angle of view as shown on the background image respectively. The dash-line triangle outlines three data collection positions that were arranged in a triangulation manner. The solid line indicates that the two viewpoints should be connected for free navigation, while the dash-line rectangle indicates that the two viewpoints should not be connected due to the altar between them. The pinpointed numbers in blue color show the praying sequence.

considered redundant were removed from the VT. Third, the intangible data were geotagged onto the VT using pushpins attached to points of interest such as the deities and the couplets on the pillars. Being culturally sensitive was a key consideration for the places of the pushpins. All the pushpins with respect to deities were therefore attached below the respective deities statues rather than overlaid onto them.

The creation of pushpins required further manipulation with the addition of occlusion and see-through boxes to ensure that the pushpins could be properly obscured or anchored in place. Specifically, an issue that surfaced was the pushpins being visible when they should not have been visible. For example, as shown in Fig. 7a, the yellow pushpin can be seen despite its placement behind the pillar. The creation of occlusion boxes (Fig. 7b) ensures that the pushpins are obscured from the users view at viewpoints where the pushpins should not be visible (Fig. 7c). Another issue that surfaced upon the inserting of pushpins was the obscuring of the pushpins from views where they should have been visible. To address this issue, see-through boxes, which perform the opposite function of occlusion boxes, were created to make the pushpins visible at viewpoints where the users are supposed to see them. Lastly, 3D numbers in blue were created based on the suggested worshipping sequence (Fig. 6). For instance, the second group of deities (Lords *Zhu*, *Xing*, and *Li*) on this sequence is shown to be in the middle of the indoor hall while the third deity to pray (*Tua Pek Kong*) is located at the right end-most of the hall.

5. Results

An interactive VT of the Tampines Chinese Temple was generated, which can be accessed via Cupix at https://players.cupix.com/p/fK5O32HV. A video capturing a user's experience of the VT is available at https://www.youtube.com/watch?v=UoQ69p8c0gA. Blue numbers attached in proximity to the thirteen praying spots depict the suggested worshipping sequence by the temple secretary to guide the users effectively in the indoor navigation.

Fig. 8 shows an illustration of the historical and socio-cultural information associated with the deity, which we have geo-tagged onto the altar of the deity statues using a yellow pushpin. A floorplan is embedded at the lower-left to provide a spatial reference for the user. To provide a condensed form of the historical and socio-cultural information associated with each deity, the following semantic information was sieved out from the temple publications and interviews with the temple secretary. These include the name of the deity, the original temple of the deity (if applicable), the significance of praying to the deity, the spatial location of the deity within the temple as well as the appropriate number of joss sticks to be used for praying to the deity. In addition, historical photographs illustrating the deity in its original subsidiary temple, obtained from the NAS and the publications produced by the Tampines Chinese Temple, were embedded to provide a visual element portraying the historical context. In addition, the VR capability in-built in Cupix can be activated by clicking the goggle icon on the top-left corner of the system interface (Fig. 8), offering users an immersive experience within the temple (Fig. 9).

6. Discussion

6.1. Implications

This article contributes to the literature on cultural heritage preservation by presenting a detailed methodological framework for the creation of VTs. In addition to preserving the temples architectural integrity (i.e. the tangible built environment), it also documents the historical and socio-cultural knowledge related to the temple. Through our informal conversations with the temple secretary, numerous media personnel and students have written about the temple in lieu of its heritage significance accorded by NHB (2018). However, these prior attempts at documenting

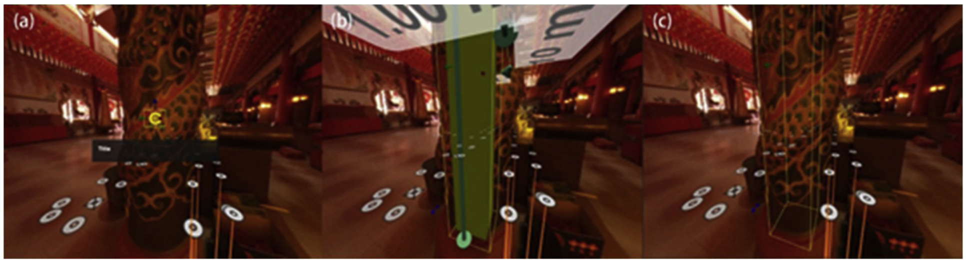

Fig. 7. a: Indoor environment of the temple without any occlusion box; b: Creation of an occlusion box (the green box); c: Indoor environment of the temple after adding the occlusion box.

Fig. 8. Screenshot illustrating the system interface and geotagged information.

Fig. 9. Two identical views enabled when the VT goggles mode is activated.

the temple disproportionately emphasised the history of the oldest subsidiary temple among the twelve subsidiary temples. Our study differs from these attempts by creating a VT that depicts the temples heritage more comprehensively – visually, spatially, and semantically. It is an appealing platform that showcases the temples historical and socio-cultural information rather than merely presenting a copy of its physical structure. It equips users with a more in-depth understanding of the temples cultural heritage, and will no doubt be very helpful for users to acquire a deeper understanding of the broader Taoist culture (e.g. religious practices). In so doing, the VT preserves the temples cultural heritage holistically.

The VT also serves as a useful pedagogical tool for the transmission of the knowledge to the young generations of ethnic Chinese Singaporeans. While offering an immersive temple experience for the younger generation, the VT can also potentially evoke their curiosity about the traditional Chinese culture and subsequently attract them to visit the temple on-site. The usefulness of the VT is acknowledged by the temple secretary in his feedback on the VT. As the temple secretary pointed out, the VT is beneficial for the temple as it can attract both local and international devotees. The donations from a larger pool of devotees could enhance the temples financial sustainability. Apart from attracting devotees, the information-enriched VT may also attract tourists who are interested in cultural heritages but are not familiar with the temple. In contrast to Guttentags [42] emphasis on the potential of VT in reducing the risk of a heritage site suffering from wear and tear by serving as a substitute to on-site access, the temple secretary instead highlighted our VT's advantage of increasing the number of visitors to the temple. Moreover, the local tour guides are required to be well-versed in their knowledge of the Tampines Chinese Temple. Without the VT, they are only able to acquire knowledge about the temple by reading the publications produced by the temple, which is time-consuming. While information on the temple can also be retrieved by accessing the temple's website [35] and the heritage trail [36], both platforms lack the spatial visualisation dimension.

6.2. Difficulties and future work

The inevitable trade-off between the quality of the virtual surface and the processing speed was a challenge we encountered. To allow for all-rounded navigation and more complete geotagging of information to the deities and objects of interest, which would improve the pedagogical value and cultural records of the temple space, we added more images taken using the 360° camera. However, with the addition of these images, the VT suffered from lag. Future work applying our method should consider the use of higher-end devices with stronger computational power and higher memory storage to generate VTs using a large volume of images.

Given that spherical images were taken and used in creating the VT, it was inevitable that the tripod stand would be visible when the view was directed towards the ground. The mitigation effort was to paste the logo of the research teams institute at the nadir of the images to serve the dual purposes of concealing the tripod stand and acknowledging the institution with which the research team has carried out the project. Incorporating the VT into established navigational interfaces such as Google Street View will boost the accessibility of the tour. To better address the limitation of low-resolution images captured of the tangible structure of the temple (or other cultural heritage sites) above eye-level using the 360° camera, future work could also explore the use of drones.

7. Conclusion

This work addresses the disproportionate emphasis on documenting the built environment of cultural heritage sites in the literature on heritage management. We have achieved this by presenting a detailed methodological framework that not only preserves the physical structures but also considers the intangible socio-cultural elements associated with cultural heritage sites. Our proposed approach is advantageous because of its high accessibility. The likelihood of cost being a barrier to future applications of our method is low due to the relatively low pricing of the Cupix software. Furthermore, the use of a 360° camera and digital single-lens reflex camera, which does not require a high level of technical expertise in comparison to other digital and visualisation technologies, also encourages stakeholders (namely heritage practitioners) to replicate our VT. Referencing from multiple sources such as interviews with personnel involved in the management of heritage sites (e.g. the temple secretary in our context) as well as historical archives (across different scales - national or heritage site-specific) enhances the credibility of this method. As we embrace the digital age, it is crucial for heritage practitioners to explore ways such as the creation of VTs to effectively disseminate knowledge related to (in)tangible cultural heritage to visitors and users of heritage.

Acknowledgments

We acknowledge the funding support from the National University of Singapore Humanities and Social Sciences seed grant (R-109-000-224-646) and Singapore Ministry of Education Academic Research Fund (MOE2015-T2-2-135). The funding sources have no involvement in study design, collection, analysis and interpretation of data, writing of the report, and the outlet of the manuscript. We gratefully acknowledge and thank the National Heritage Board (NHB) in Singapore for granting us permission to reproduce and adapt the Tampines heritage trail map for our publication. This article benefited enormously from the generous and constructive comments of three anonymous reviewers. We would also like to thank Juen Tan for his assistance rendered in this research.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at https://doi.org/10.1016/j.culher.2019.04.004

References

[1] J.E. Tunbridge, G.J. Ashworth, Dissonant heritage: the management of the past as a resource in conflict, J. Wiley, New York, Chichester, 1996.
[2] B. Graham, G.J. Ashworth, J.E. Tunbridge, A Geography of Heritage: Power, Culture & Economy, Arnold, Great Britain, 2000.
[3] B. Yeoh, Postcolonial cities, Progr. Hum. Geography 25 (3) (2001) 456–468.
[4] J.E. Tunbridge, Whose heritage to conserve? Cross-cultural reflections on political dominance and urban heritage conservation, Can. Geographer 28 (2) (1984) 171–180.
[5] D. Hardy, Historical geography and heritage studies, Area 20 (4) (1988) 333–338.
[6] D. Harvey, Heritage pasts and heritage presents: temporality, meaning and the scope of heritage studies, Int. J. Herit. Stud. 7 (4) (2001) 319–338.
[7] L. Smith, Uses of Heritage, Routledge, New York, 2006.
[8] D. Viejo-Rose, M.L.S. Sørensen, Cultural heritage and armed conflict: New questions for an old relationship, in: E. Waterton, S. Watson (Eds.), The Palgrave Handbook of Contemporary Heritage Research, Houndmills, Basingstoke, Palgrave Macmillan, Hampshire, 2015, pp. 281–296.
[9] P. Groote, T. Haartsen, The communication of heritage: Creating place identities, in: B. Graham, P. Howard (Eds.), The Ashgate Research Companion to Heritage and Identity, Ashgate Publishing Company, Burlington, VT, 2008.
[10] G. Aplin, Heritage: Identification, Conservation and Management, Oxford University Press, South Melbourne, 2002.
[11] M. Economou, Heritage in the digital age, in: W. Logan, M. Nic Craith, U. Kockel (Eds.), A companion to heritage studies, Wiley-Blackwell, Chichester, West Sussex, UK, Malden, MA, 2015, pp. 215–228.
[12] A.A. Núñez, P.F. Buill, M.J. Regot, G.A. de Mesa, Generation of virtual models of cultural heritage, J. Cult. Herit. 13 (1) (2012) 103–106.
[13] A. Guarnieri, F. Pirotti, A. Vettore, Cultural heritage interactive 3D models on the web: An approach using open source and free software, J. Cult. Herit. 11 (2010) 350–353 (Elsevier BV).
[14] D.M. Campanaro, G. Landeschi, N. DellUnto, A.-M. Leander Touati, 3D GIS for cultural heritage restoration: A white box workflow, J. Cult. Herit. 18 (2016) 321–332.
[15] C.L. Ogleby, The "Truthlikeness" of virtual reality reconstructions of architectural heritage: concepts and metadata, ISPRS 34 (2005) 192–199.
[16] E. Champion, The Role of 3D Models in Virtual Heritage Infrastructures, in: A. Benardou, E. Champion, C. Dallas, L. Hughes (Eds.), Cultural Heritage Infrastructures in Digital Humanities, 1st ed., Routledge, Abingdon, Oxon, 2018, pp. 15–35.
[17] N. Yastikli, Documentation of cultural heritage using digital photogrammetry and laser scanning, J. Cult. Herit. 8 (4) (2007) 423–427.
[18] M. Murphy, E. McGovern, S. Pavia, Historic building information modelling – adding intelligence to laser and image based surveys of European classical architecture, ISPRS 76 (2013) 89–102.
[19] E. Colucci, F. Noardo, F. Matrone, A. Spanò, A. Lingua, High-level-of-detail Semantic 3D GIS For Risk and Damage Representation of Architectural Heritage, ISPRS XLII-4 (2018) 107–114.
[20] A. Agapiou, V. Lysandrou, D.D. Alexakis, K. Themistocleous, B. Cuca, A. Argyriou, A. Sarris, D.G. Hadjimitsis, Cultural heritage management and monitoring using remote sensing data and GIS: The case study of Paphos area, Cyprus, Computers, Environ. Urban Syst. 54 (2015) 230–239.
[21] F. Apollonio, V. Basilissi, M. Callieri, M. Dellepiane, M. Gaiani, F. Ponchio, F. Rizzo, A. Rubino, R. Scopigno, G. Sobra, A 3D-centered information system for the documentation of a complex restoration intervention, J. Cult. Herit. 29 (2018) 89–99.

[22] M. Lezzerini, F. Antonelli, S. Columbu, R. Gadducci, A. Marradi, D. Miriello, L. Parodi, L. Secchiari, A. Lazzeri, Cultural heritage documentation and conservation: three-dimensional (3D) Laser Scanning and Geographical Information System (GIS) Techniques for Thematic Mapping of Facade Stonework of St. Nicholas Church (Pisa, Italy), Int. J. Archit. Herit. 10 (1) (2016) 9–19.

[23] M. Lazzari, M. Danese, N. Masini, A new GIS-based integrated approach to analyse the anthropic-geomorphological risk and recover the vernacular architecture, J. Cult. Herit. 10 (2009) e104–e111.

[24] F.T. Gizzi, M. Sileo, M. Biscione, M. Danese, M. Alvarez de Buergo, The conservation state of the Sassi of Matera site (Southern Italy) and its correlation with the environmental conditions analysed through spatial analysis techniques, J. Cult. Herit. 17 (2016) 61–74.

[25] K. Popper, Objective knowledge: an evolutionary approach, Clarendon Press, Oxford, 1975.

[26] P. Chias, T. Abad, E. Echeverria, F.D. Casa, F. Celis, A GIS in Cultural Heritage based upon Multiformat Databases and Hypermedial Personalised Queries, Athens, Greece, XXI International CIPA Symposium, 01-06 October (2007) 1–5.

[27] L. Hua, C. Chen, H. Fang, X. Wang, 3D documentation on Chinese Hakka Tulou and Internet-based virtual experience for cultural tourism: a case study of Yongding County, Fujian, J. Cult. Herit. 29 (2018) 173–179.

[28] R.K. Napolitano, G. Scherer, B. Glisic, Virtual tours and informational modeling for conservation of cultural heritage sites, J. Cult. Herit. 29 (2018) 123–129.

[29] F. Bruno, S. Bruno, G. De Sensi, M. Luchi, S. Mancuso, M. Muzzupappa, From 3D reconstruction to virtual reality: a complete methodology for digital archaeological exhibition, J. Cult. Herit. 11 (1) (2010) 42–49.

[30] Google LLC. (2019). Google Arts & Culture - Apps on Google Play. Available at: https://play.google.com/store/apps/details?id=com.google.android.apps.cultural&hl=en [accessed: 22 February 2019].

[31] Google Arts & Culture, in: Singapore Art Museum, Google Arts & Culture, 2019 https://artsandculture.google.com/partner/singapore-art-museum (accessed: 22 February, 2019).

[32] Google Arts & Culture, in: Mt. Mitoku Sanbutsu ji Temple, Google Arts & Culture, 2019 https://artsandculture.google.com/partner/mt-mitoku-sanbutsu-ji-temple (accessed: 22 February, 2019).

[33] Richards-Rissetto H., Robertsson J., von Schwerin J., Agugario G., Remondino F., Girardi G. (2013). Geospatial Virtual Heritage: A Gesture-Based 3D GIS to Engage the Public with Ancient Maya Archaeology, Anthropology Faculty Publications, 62, http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1065&context=anthropologyfacpub (accessed: 22 February 2019).

[34] Mohan M. (2018). NDR 2018: Singapore to nominate hawker culture as intangible cultural heritage for UNESCO listing. https://www.channelnewsasia.com/news/singapore/ndr-2018-singapore-nominate-hawker-culture-unesco-heritage-10631126 (accessed: 22 February 2019).

[35] Tampines Chinese Temple (n.d.). Tampines Chinese Temple 淡滨尼联合宫 Dan Bin Ni Lian He Gong, Available at: http://www.beokeng.com/disptemple.php?temple=tampines-chinese-temple [accessed 22 February 2019].

[36] National Heritage Board (2017). Tampines Heritage Trail - Tampines Town Trail. www.roots.sg. Available at: https://roots.sg/Roots/visit/trails/Tampines-Heritage-Trail-Tampines-Town-Trail (accessed: 22 February 2019).

[37] H.M. Yilmaz, M. Yakar, S.A. Gulec, O.N. Dulgerler, Importance of digital close-range photogrammetry in documentation of cultural heritage, J. Cult. Herit. 8 (4) (2007) 428–433.

[38] Tampines Chinese Temple (1991). Tampines Chinese Temple: Celebrating its Establishment (Special Edition), Xinjiapo: Danbinni lian he gong chou bei jian gong ji jin wei yuan hui. (in Chinese: 淡滨尼联合宫 (1991). 淡滨尼联合宫:庆城典礼纪念特刊).

[39] Tampines Chinese Temple (2001). Tampines Chinese Temple: Celebrating Ten Years of Merger of Subsidiary Temples (Special Edition), Xinjiapo: Danbinni lian he gong chou bei jian gong ji jin wei yuan hui. (in Chinese: 淡滨尼联合宫 (2001). 淡滨尼联合宫:晋宫十周年纪念特刊).

[40] Tampines Chinese Temple (2012). Seeing the Present over 20 years, Xinjiapo: Danbinni lian he gong chou bei jian gong ji jin wei yuan hui. (in Chinese: 淡滨尼联合宫 (2012). 或耀二十载:龙飞看今朝).

[41] D. Guttentag, Virtual reality: applications and implications for tourism, Tourism Manag. 31 (5) (2010) 637–651.