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Case study

3D documentation on Chinese Hakka Tulou and Internet-based virtual experience for cultural tourism: A case study of Yongding County, Fujian

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ABSTRACT

Hakka culture, the material and spiritual wealth of the Hakka, originated in Xijin Dynasy (266 AD) and manifests in the forms of language, folk customs, architecture, relationship, etc. Yongding County, the Hakka culture resorts, are attracting more and more tourists home and abroad over the past few decades in China. Known as the living fossil of the ancient Chinese culture, Hakka culture has not been well studied and Tulou (Hakka Earth Buildings), which still inhabited by the Hakka as their traditional and permanent house, have been poorly maintained. In this paper, a practice of 3D documentation on the Chinese Hakka culture within Yongding County, Fujian Province by a multidisciplinary approach was conducted, and an Internet-based virtual experience system for tour purpose was presented. First, the materials and knowledge of Hakka culture was surveyed and collected on site, including historical evolution, Tulou or its ruins or remains and folk customs. Then, the data sets associated with Tulou from terrestrial laser scanner, unmanned aerial vehicle and digital camera, are integrated in order to model in 3D realistic manner. Finally, an internet-based cloud-enabled 3D geographic information service system for Hakka culture (HCGISS) was developed with data storage on cloud end and service functions, such as scene loading and browsing, thematic cultural maps display, information query and online virtual experience for tour, tourist route navigation to users on browser end. The system provides the Internet-based virtual experience for cultural tour in 3D interactive way and a novel platform for Hakka culture presentation, cognition and heritage as well. It is helpful to awaken the public's awareness to protect the traditional unique Hakka culture.

1. Introduction

Chinese Hakka culture has a great tourism potential in both aspects of its tangible and intangible heritages. It is now becoming an important cultural resort in China. Hakka culture is distinctive and famous for its historical origins, buildings, folk customs and interpersonal relationship. In 2008, forty-six Tulous, which have prolific symbolic culture, were added to the UNESCO World Heritage List [1]. Hakka culture, however, has not been well studied and some Hakka Tulous were poorly maintained or uninhabited, some of which were even damaged due to anthropogenic and natural factor, and expensive maintenance.

The problems mentioned above motivated the following research funded by National Science and Technology Support Plan (No. 2013BAH28F00), as a part of Cultural Heritage Digitization and Cultural Tourism Comprehensive Service. The program aims to take a pioneer study of Yongding County, Fujian province, in addition, investigate and document 23 of 23,000 Tulous in Yongding which were listed in the UNESCO World Heritage List.

Besides physical protection measures, 3D documentation and virtual exhibition is a new effective way to preserve and exploit ancient building and culture. In order to obtain a precise representation of large complex historic sites, it is necessary to combine the different techniques [2]. Remondino et al. reviewed the heritage digitization pipeline, reported the guidelines and best practices from a large collection of publications [3]. We can conclude that the integration of laser scanning [4–7] and digital photogrammetry [8,9] assists to obtain accurate 3D metrical models for the

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presentation and interpretation even under unfavorable conditions. Reality-based modeling stressed the importance of utilizing 3D technologies [10]. But a best pipeline is extremely difficult to be defined, the adoption of a sole methodology of acquisition may reveal profitable for some aspects but incomplete for others [11]. The geometric shape of Hakka Tulou is complex, irregular and in many details. What is more, there still live many indigenous residents in Tulou and household items are located in situ in random manner. These conditions make the digitization of Hakka Tulou rather difficult.

Furthermore, the 3D models should be used not only by specialized scholars, but also by common visitors. So the way to build large-scale virtual tourism systems comprehensively on Web and mobile browsers were analyzed. While, each historical building is by definition unique, all the recommendations suggest that the cultural implications of these buildings must be the starting point before any conservation and tourism [12]. Reality-based reconstruction, such as visualization techniques for indoor [13], and in situ applications [14], represents the medium through which the wide public deepen and improve the knowledge of history and architecture.

Internet-based virtual experience for cultural tourism has an increasing importance in establishment of inter-culture communication and sharing cultural heritage. The aim of this research is to obtain the materials and knowledge of Hakka culture and illustrate a case study of a workflow for documenting Hakka Tulou, and perform the combination of Hakka culture and realistic 3D digital representations for Internet-based interactive virtual experience and cultural tourism information services.

2. An overview of Hakka culture

2.1. Historical evolution

The Hakka has been intriguing the Chinese people for more than 2000 years. These people originally inhabited in Central Plain. Due to war or (and) famine, they began to migrate southward for an enormous distance, which occurred in various stages. Nowadays, they are widely distributed in southern China and Southeast Asia [15–17]. Hakka is characterized by its unique intrinsic culture [18,19]. Cultural assimilation, however, could not be avoided. In the process of their southward migration and later colonization in southern China, they were also shaped by local culture, e.g. patrilocality.

The ancient Hakka' s migration took place on several stages. According to the historical references [20], there are five major migration waves of the Hakka (shown in Fig. 1). And the triggers behind are multiple. The first great migration was due to the invasion by five minorities in the Xijin Dynasty (265–316 AD). The second big migration was the result of Huangchao Uprising in the near end of Tang Dynasty (618–907 AD). The invasion of Jin Kingdom in Song Dynasty (960–1279 AD) caused the third great migration. And the fourth great migration took place after the Manchurians became the ruler in China [21]. The fifth migration was to search a greater space for the future development.

2.2. Hakka Tulou

After each migration, Hakka built Tulou (Hakka Earth Buildings), known as the ancient castle of the orient, are the unique rural

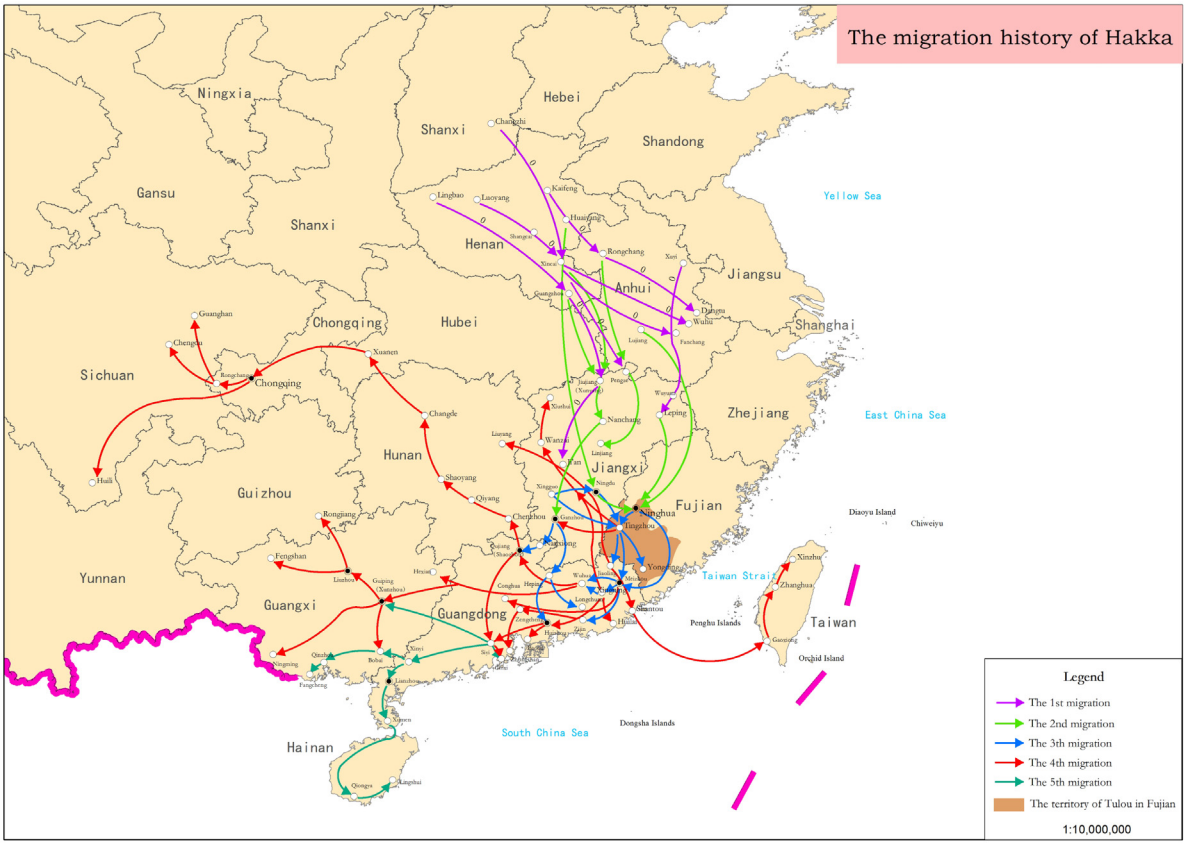

Fig. 1. The five major migration routes of Hakka.

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Table 1
Thematic maps list of Hakka folk culture.

Thematic map	Map scale	Transaction year
Hakka language distribution in China	1:4000,000	2000
Hakka ancient buildings in West Fujian	1:250,000	2016
Hakka traditional customs in Fujian	1:250,000	2016
Hakka traditional festival in West Fujian	1:250,000	2016
Hakka dietary culture in West Fujian	1:250,000	2016
Hakka music and drama in West Fujian	1:250,000	2016
Hakka acrobatics and arts in West Fujian	1:250,000	2016
Hakka manual craftsmanship in West Fujian	1:250,000	2016

dwellings and former fortifications of the Hakka in mountainous area, and normally appear in clusters to keep from bandits and beasts [22]. There are over several ten thousands of Hakka Tulous in the bordering regions of Fujian, Jiangxi and Guangdong provinces, with a greatest concentration in Yongding County, Fujian (shown in Fig. 1).

The thick outer walls of Tulou were made of rammed earth nearby, and used to defence arrows and gunfire from the foreign invaders. Some bamboo strips, firs and special ingredients (brown sugar, egg whites and sticky rice) were put into the wall to strengthen its tension and seismic resistance capability [23]. Most of Tulous, normally with three to four storeys in height, ranging in size 14–100 meters in diameter, could accommodate at most 80 families or several hundreds of residents [24]. To resist a foreign enemy, there was no window on the 1st and 2nd floor of Tulou except few hard entrance doors, and water tanks equipped on top of the door to put out fires set by the enemy.

On the one hand, these Tulou's construction followed the particular style of "harmony between man and nature", which is a core doctrine for the Oriental philosophy and geometrical layout with the axis as the symmetry. On the other hand, emphasis on the special contrast design made the whole structure extraordinarily perfect according to the Chinese balance of ancient Yin and Yang theory, and is a full demonstration of an ingenious combination of high technology and nature [25]. As the "exceptional examples of a building tradition and function exemplifying a particular type of communal living and defensive organization in a harmonious relationship with their environment" [26], the traditional Hakka buildings appear to be unique and distinguished ones in the art of architecture.

2.3. Folk customs

Nowadays, folk culture has been an important resource in tourism industry. The experiences of folk customs of the Hakkas are always appealing. As one of six major civilian systems in south China migrated from central China, Hakka not only inherited the traditional folk customs of Han nationality, but also developed a unique folk customs by combining and permeating with various local ones during the long time migrations [27–29]. For instance, the most special folk arts is the Chinese couplets pasted on the sides of door in Tulou, the content of the couplets usually is associate with family precepts and reflects the spirit of Hakka inherited for many thousand years. In addition, stone carving, wood carving and murals in Tulou are also filled with the breath of art.

Serial thematic maps (seen as Table 1), text, images, audios, videos and realistic models are employed to reflect tangible and intangible Hakka folk culture, including religious culture (such as festivals, sacrifice, marriage custom, farming, dress and etiquette), local dialect, art (such as poems, music, gongs), education, drama (such as Hanju, puppetry), industrial and agricultural production (such as tea, buildings), folk handicrafts (such as dried vegetable, cigarette, rice wine, "Fubanglu", pots, hats, wind mill) and so on. For more information, please visit our virtual tour website – www.whlyw.net.

3. Realistic modeling

3.1. Data acquisition

Any cultural heritage (including its ruins or remains) always situated on a real and complex three dimension geographical environment or landscape, which can be depicted by topography, geomorphology, vegetative cover, etc. In our case study, the basic geographical data, such as Digital Elevation Model (DEM) and Digital Orthophoto Map (DOM) with high resolution (enough to positioning 3D models) were used to describe 3D geographical environment in Yongding county. The original 1:10,000 DEM data were obtained in 2014 from Fujian Surveying and Mapping Institute. And DOM (with the resolution of 0.2 m and 0.05 m) was further processed from the aerial photographs around the Hakka Tulou by Unmanned Aerial Vehicles (UAVs).

Terrestrial laser scanner (TLS) was used to gain point cloud for the important Hakka Tulou listed in the UNESCO World Heritage. In our study, a Riegl VZ-400 (shown in Fig. 2) with a 400 m measurement range was used to get the point cloud data from the external

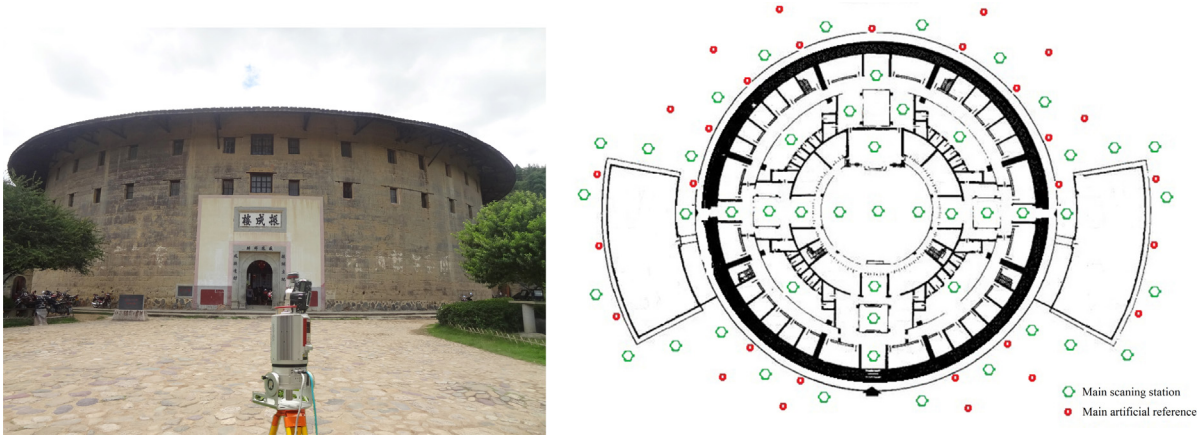

Fig. 2. The photos from Scanning Zhencheng Building using Riegl VZ-400 (left) and main scanning stations scenario (right).

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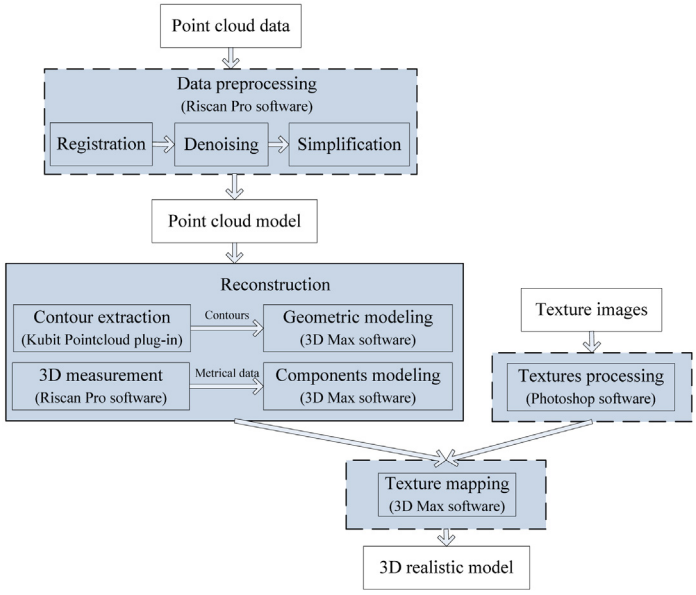

Fig. 3. 3D modeling procedure of a Tulou.

and indoor surfaces of Tulou. The expected accuracy is less than 5 mm at distance of 100 m, and angular resolution is 0.0005°. Artificial reflected targets were needed additionally to improve the registration precision among the scanning stations, which is made of special material in high reflectivity. The distance between reference point and laser scanner is generally within 80 m, and especially 30–50 m is required under severe environment. As shown in Fig. 2, there were 66 scanning stations for Zhencheng Building, which is the "Prince" of Tulou.

3.2. 3D reconstruction

The original point cloud data must be pre-processed first, including registration, denoising and simplification. And then the contours were extracted based on point cloud to reconstruct the geometric model. Finally, texture mapping was used to apply textures to polygons to improve the reality of models. The overall procedure is shown in Fig. 3.

Registration among multi-stations was implemented by Riscan Pro software within 0.005 m. After registration, the data size of one Tulou was found to be huge (e.g. Zhencheng Building, 50 GB). Meanwhile, plants and groceries around or inside Tulou produced noise points. Consequently, we used Riscan Pro software to remove the noise data and simplify the point clouds.

As the pros and cons of the things, the removal of plants and groceries should result in the production of holes, and photos at the same perspective were used to assist modelling. First, Kubit Pointcloud (a plug-in of AutoCAD) was used to extract the contours. After the point clouds are sliced, serial subsets of the registrated point cloud (namely slicing data in term) were used to curve fitting. The

Fig. 4. A comparison among the photo, geometrical model and realistic 3D model of Zhencheng Building in the view of external (up) and indoor (down). a: the original photo; b: geometric model; c: realistic 3D model.

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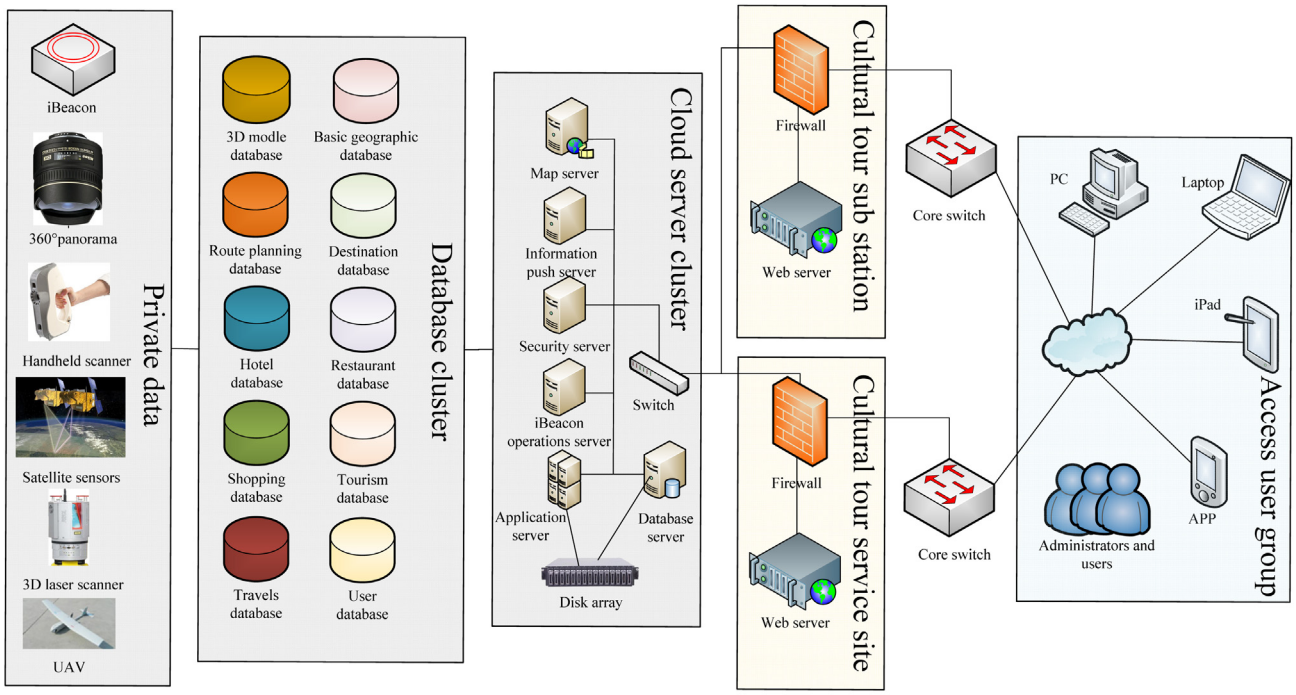
basic principle of space geometry (such as intersecting line get from two meeting surfaces, etc.) and photos at the same perspective were applied to get the missing feature points and lines. Second, the contours were imported into 3D max to reconstruct the geometric model of Tulou. In order to improve the modelling efficiency, some similar parts inside Tulou (such as stairs, guardrails, engraved wooden doors, etc.) were modelled into components based on the metrical data from point cloud and integrated with Tulou based on the photos.

Texture mapping is the most important process for realistic 3D modelling. The best time to capture texture image is from 10:00 am to 3:00 pm local time, in order to avoid the shadow of the building affecting the integrity of the texture. We used the Photoshop software to process the original images to textures. A comparison among the photo of Hakka Tulou, geometrical model and realistic 3D model is shown in Fig. 4.

4. Virtual cultural tourism

4.1. Cloud-enabled data storage

As depicted in Section 2, the data types related to 3D documentation of cultural heritage are various, huge and complex in format, normally including the georeferenced, such as topography, geomorphology, vegetative cover, DEM, DOM and cultural thematic layers mentioned in Section 2.3, and the non-georeferenced, such



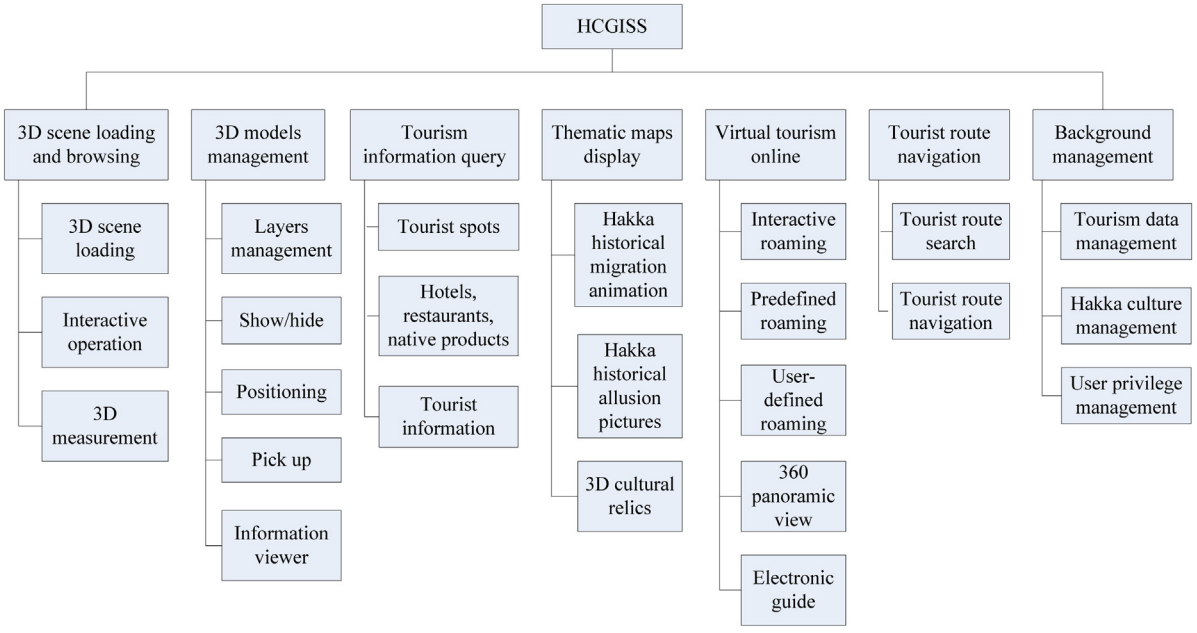


Fig. 5. The structure (up) and functional hierarchy (down) of the HCGISS.

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Fig. 6. The user interfaces of the HCGISS in Chinese. a: electronic guide; b: 3D measurement; c: the animated show of Hakka history; d: the historical allusions of Hakka culture.

as 3D models, 360 panoramic images, texts, audios and videos. The non-georeferenced data can be related to the georeferenced data inside a main stream Geographical Information System Software in brief, and can be organized and stored in similar to regular file format inside back-end database system. In order to simplify the problem, here only the geospatial data will be discussed in brief. Considering the types and characteristics of geospatial data and for purpose of the reliability and availability of the access to geospatial data, an architecture of cloud-enabled geospatial data storage was proposed [30,31] by our team, combining cloud computing and NoSQL distributed database technology. It consists of data organization model, access mechanism and management strategy to integrate raster (e.g. remote sensing images and DEM) and vector (e.g. cultural thematic maps) geospatial data.

4.2. Hakka culture 3D geographic information service system

After documentation on Chinese Hakka culture in Yongding County, the more important work for our research is to realize there resources be accessed and exploited Hakka cultural tourism. A 3D geographic information service system (HCGISS, http://www.whlyw.net/hakkas/) was developed with a unique function of Internet-based virtual experience for cultural tourism. The structure of HCGISS is shown in Fig. 5. This system development mainly included establishment and maintenance of front-end (web) and background cloud-enabled database management module.

The front page was developed in HTML and JavaScript, the access to background data was based on the web service Description Language (WSDL) of Microsoft.NET Framework 4.0. And the background database management module was developed in SQL Server 2008. SuperMap iServer was used as web server for deploying geographic data and displaying 3D realistic models in 3D scene at the front-end.

The main function hierarchy of HCGISS is shown in Fig. 5. And the main feature of the HCGISS is summarized below.

- real-time interactive operations with large models in 3D environment, such as 3D model pickup, location labeling and 3D measurement (seen in Fig. 6b);
- cultural thematic information and maps of Hakka are performed. The content of Hakka culture in text, photo, audio and video format are embedded and presented in seamless integration (seen in Fig. 6c and d);
- the intelligent tourism planning and personalized APP. Virtual tourism online is realized through the predefined or user-defined roaming as well as location-aware electronic guidance module (seen in Fig. 6a) and sequential 360 panoramic images;
- location-aware information push indoor and outdoor;
- integration of virtual reality, GIS and real experience technologies. The system provides the loading operation for multi-resolution geospatial data, and the smooth browsing in WEB environment.

To evaluate the HCGISS, one considers the educational value of the site. The results of questionnaires used for user studies were presented in Table 2. The total number of valid return was 1739, we found most of the users agree that the site is helpful and significant.

Table 2
Questionnaire results of HCGISS used for user studies.

Questions	Agree (%)	Not sure (%)	Disagree (%)
The tourism information in site is useful to you	83	12	5
The site helps you to further understanding the Hakka culture	94	5	1
The virtual experience of Tulou is attractive to you	89	7	4
Tulou needs to be protected	98	1	1
Hakka culture needs to be inherited	98	1	1

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5. Conclusions and future work

In this paper, the unique Hakka cultural content, charm and value are discussed as background knowledge. A multidisciplinary approach to document Chinese Hakka culture and Tulou in Yongding county, Fujian province was delineated and practiced, with a novel platform for internet-based cloud-enabled virtual experience of cultural tour in 3D interactive way.

As the comprehensive documentation and content mining of Hakka culture have not been previously reported, it is the first attempt to develop a 3D geographic information service system and virtual tourism with the theme of Hakka culture. It is helpful to awake the public's awareness to protect the traditional unique Hakka culture.

In next step, we will focus on improving widespread public communication using web and mobile devices, such as personalized recommendation, personalized tourism planning and personalized information push. To enrich the destinations or attracts is also an important task for our future work.

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