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## **Recommendations, Comments, Ideas, Details & Photos** **for the *Plan of Field Study* on Hakka Tulous**

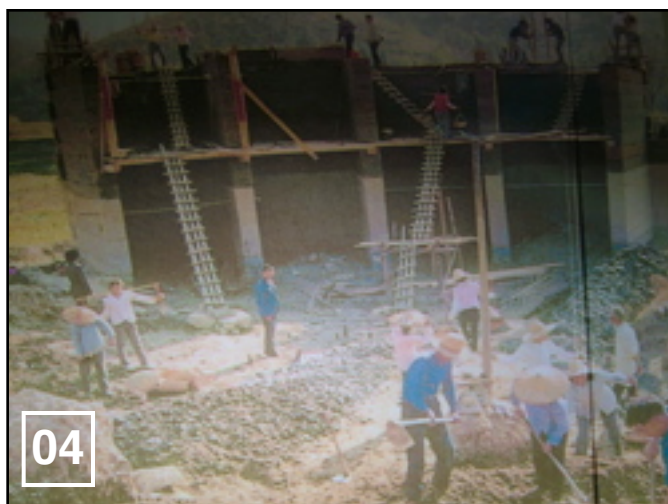
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**A) General Recommendations:** My recommendations on this study are as follows:

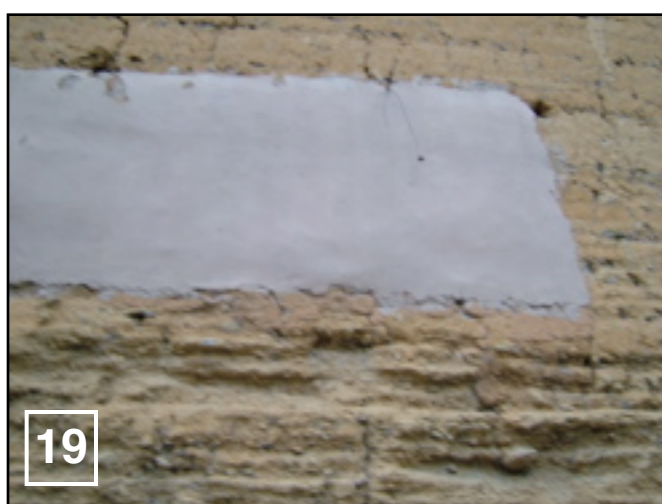
- 1) **Recommendation #1: Tulou Location & Selection:** I would recommend that you focus on **Hongkeng** as the general location, for the practicality, efficiency and cost-effectiveness of your present study. It has many (~17) buildings to choose from, as can be seen from Fig. 1, the map at Ref. 1, Ref. 2: slides 9, 10, 14, 15; Ref. 3: slide 4, 34). It is the second largest UN World Heritage Site at 30 ha (Ref. 2, slide 11). Other locations further afield (Ref. 2, slides 9, 10) can be added later, if and when the project expands. The best Chinese web sites on Hakka tulous are listed in Ref. 5. I recommend you stay at Fuyu Lou (Fig. 2), a "Five-Phoenix House" built in 1882, with 228 rooms on 5.5 stories (Ref. 2, slide 15, 16 & 33, Ref. 4), unless team mates Minoru Ueda or Xiaoyan Yan-Li (see below) have better ideas.
- 2) **Recommendation #2: 3 local Tours:** I would strongly recommend that you consider integrating **3 local tulou tours** for the group while you are there already, to get an overview and appreciation of the existing inventory of buildings for future reference. In that way, you can see the range of dates, shapes, status, heights, constraints and "interesting" study prospects, to be better prepared for project expansion in the future, based on more thorough and holistic knowledge and understanding of the context. **Chuxi** (Ref. 2, slides 4, 9-13) has 5 large circular and 10 rectangular buildings (Ref. 3). **Gaobei Village** (5 km from Hongkeng, Ref. 4) in Gaotou town (Ref. 2, slide 4, 9-11, 17-19) should be toured because it is so close to Hongkeng and because it has a very large selection of buildings. Yijing Lou, built in 1806 in Gaobei Village, is 5 stories (Ref. 2, slides 5 & 6 (#34), 28). Chengqi Lou built in 1709 is the "King of Round Earth Buildings" with 4 circular rings, 4 stories and 400 rooms (Ref. 2, slides 5 & 6 (#28), 17, 18; Ref. 4). Gaobei Village would be a good choice for any secondary sample of buildings. **Dadi Tulou** cluster is the largest World Heritage Site at 65 ha (Ref. 2, slide 9). Its most famous tulou is Eryi Lou, in Zhangzhou City, Hua-an County, Xiandu township (Ref. 7). It is large: 4 stories high, 71 m ø (Ref. 7b), but is atypical in its design and configuration. Minoru could prepare a survey sheet to summarize specifications. I recommend that Yan organize these 3 outings before your planned trip, June 15 to July 15, 2009.
- 3) **Recommendation #3: Focus:** Please see also Section C. A few suggestions to enhance the return-on-investment for this project include the following:
  - 01) sequence of rammed earth construction: was it horizontal then vertical? (Figs. 3, 4)
  - 02) is this a method of construction for the future and why?
  - 03) what binders did they use, were they effective and do they application today? (Figs. 5, 6)
  - 04) how many buildings were reinforced, with what? Was this effective enough to apply today?
  - 05) were these buildings comfortable? Why or why not? How can the lessons be applied today?
  - 06) were these buildings sustainable? Why or why not, and how can the lessons be applied today?
  - 07) veneer (parging): importance of maintaining exterior protection for structural strength and against erosion (Figs. 7-10, 18-32)
  - 08) corners: butt or interlocking joints (with/without reinforcing) for greater strength? (Figs. 11-17)
  - 09) stone foundations: (Figs. 11-17)
    - how have they performed, since no portland cement or reinforcing was used?
    - were the foundations durable?
    - did the stones have a direction, and if so, for what purpose? (Figs. 14, 15, 17)
  - 10) walls: what are the advantages of staggering wall thickness per floor? (Figs. 33-35)
  - 11) beam pockets: is there anything to learn from beam pockets? (Figs. 36, 37)
  - 12) formwork: what can be learned about the forms and to how to improve them (Figs. 38, 39)
  - 13) rehab: structural lessons in rehabilitated tulous (Figs. 40-45)
  - 14) earthquakes: what can we learn from earthquake damage in walls (Figs. 46, 47)
  - 15) failures: what can we learn from structural failures in walls (Figs. 48, 49)
  - 16) loads: determination of the main dead and live loads both vertical and lateral







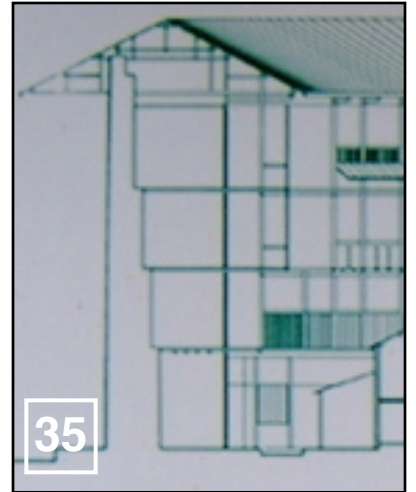




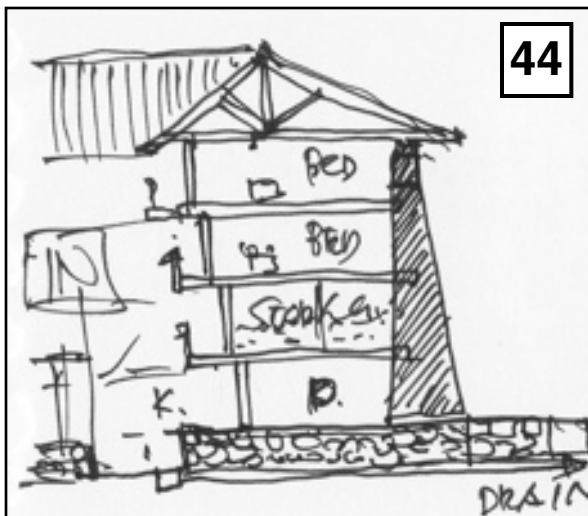




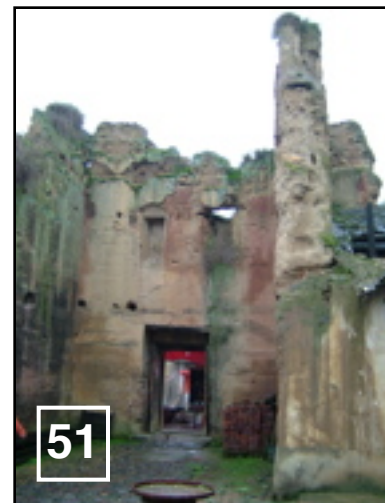








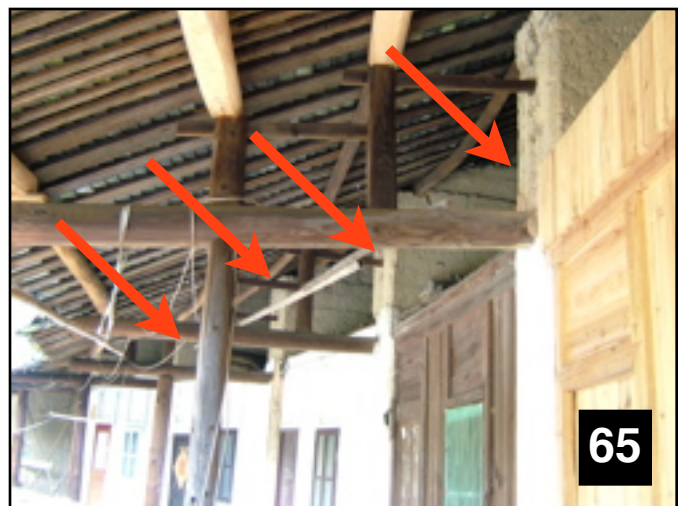
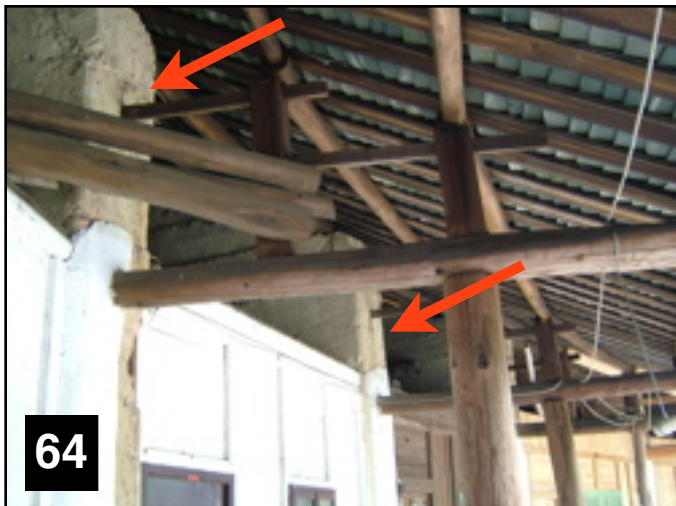




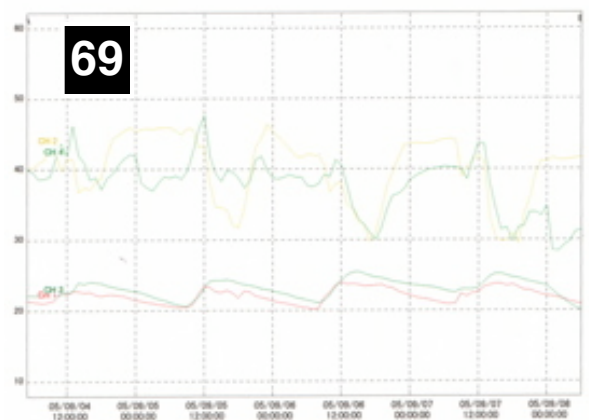








項目	測定場所	測定時間	測定結果	備考
1	1号室	05/05/04 12:00:00	25.2	25.2
2	2号室	05/05/04 12:00:00	25.2	25.2
3	3号室	05/05/04 12:00:00	25.2	25.2
4	4号室	05/05/04 12:00:00	25.2	25.2









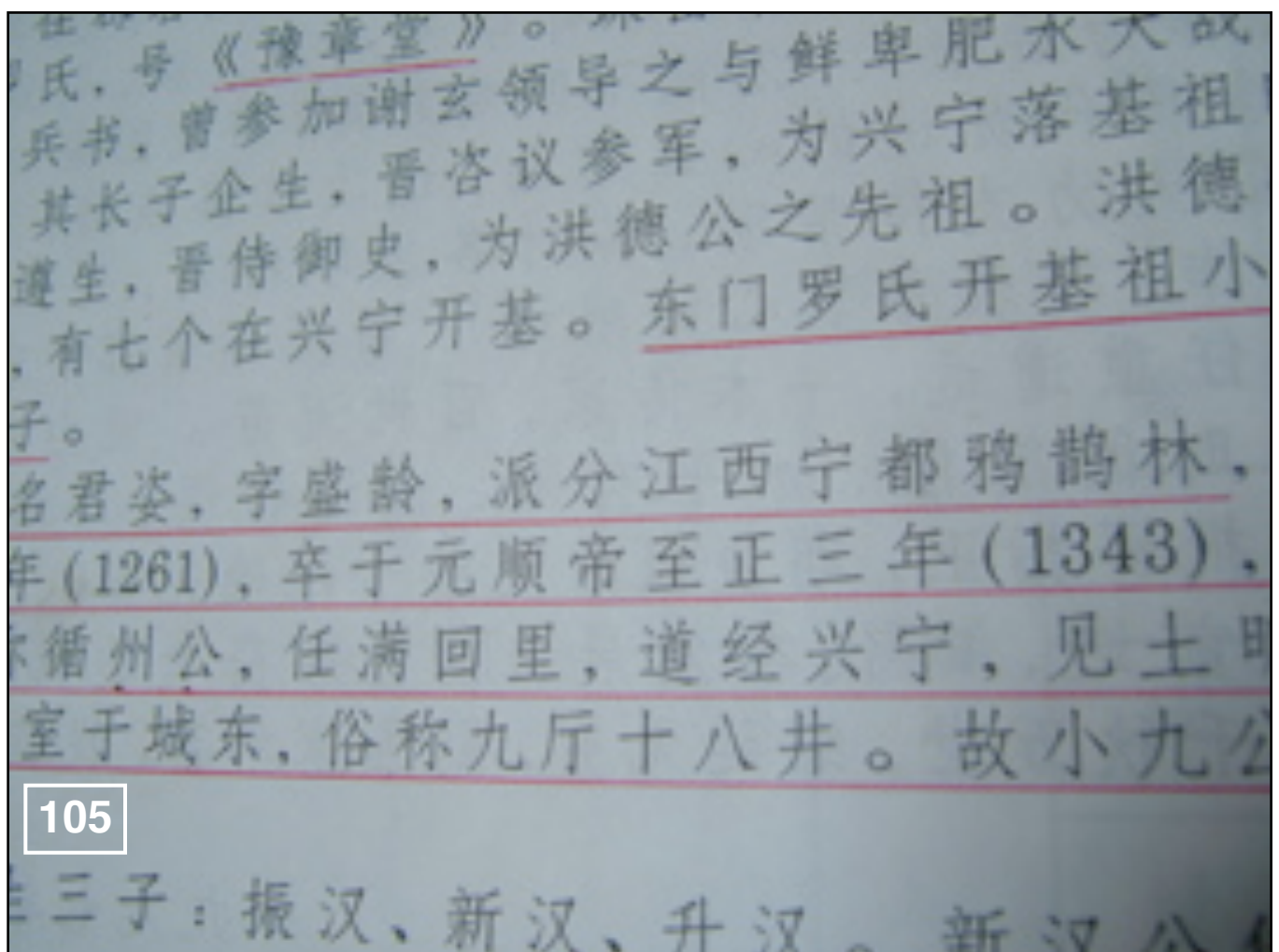
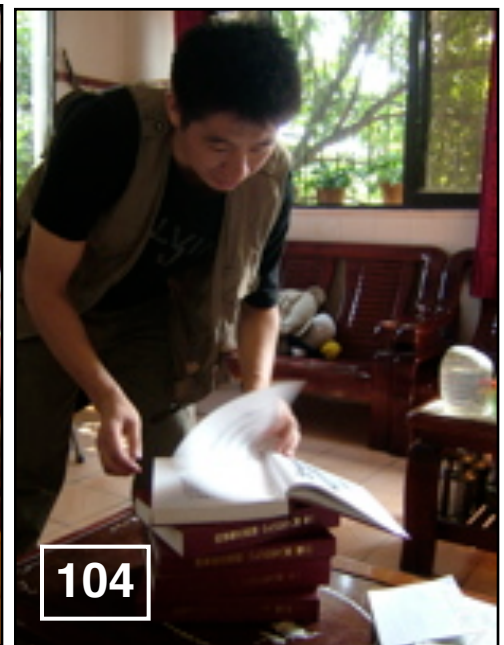












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**B) Questions & Answers:** Here are some answers to some of your questions.

- 1) **Answer #1: Yuchang Lou**, (Ref. 2, slides 5 & 6 (#6) and 35), Ref. 6, 7): Yes we have visited it in April 2007. It is now a World Heritage Site. Our information is as follows: location: Shuyang Xiaber; Family: Liu; Year constructed: 1308; Construction: 24 years; Stories: 5; Height: 21.6 m;  $\phi$ : 35 m, and Families: 21.
- 2) **Answer #2: Fuxing Lou**: I think "Fuxin Lou" should be "Fuxing Lou", which according to Minoru's *Hakka Tulou Inventory list*, is in Hulei town and was built in 769 (Ref. 2, slide 26, Ref. 4) as you state on p. 3 of your *Plan of Field Study*. It is the oldest tulou we visited. It is not a World Heritage Site. There is a square "Fuxing tulou" in Hongkeng, built in 1963 and found at: <http://amoymagic.com/FJAdv/Roundhouses.htm>
- 3) **Answer #3**: You asked if we can "...visit tulous in photos 1 & 4 for wall rib studies and Photo 4 (with Helen?) to measure wall thickness." (Figs. 33, 34, Fuxing Lou, see #2 above). Yes we can.
- 4) **Answer #4**: a) tulou built ~ 1300: need to review Minoru's *Hakka Tulou Inventory list* & references (Ref. 3)      b) tulou built ~ 1900: these decisions should be made on-site after 3 tours
- 5) **Answer #5**: a) tulous with eroded walls showing ribs: not many (Figs. 7, 8: Jiusheng; Fig. 9: Kuiju) (Ref. 21)      b) tulous not in service: most tulous are now almost abandoned
- 6) **Answer #6**: a) round tulous: many choices, review Ref. 3, Minoru's *Hakka Tulou Inventory list*      b) square tulous: many choices, make decisions on-site after tours
- 7) **Answer #7**: "We like to do some testing on interesting Tulous like Zigzag Yuchang Lou. Jorg - Please let me know any other Tulous of this nature you visited for our consideration." I agree that such anomalies are "interesting", but since taxpayer's money is being used, may I suggest that you keep your initial studies to "**typical**" Hakka buildings to enable you to show the greatest return on government investment, and to enhance future funding. That way pedagogy and scholarship is enhanced by the lessons you contribute to society in that it is able to apply to many more typical Hakka buildings. Replication and wider scope of application, is the key to government funding.
- 8) **Answer #8**: We have been to **Huanji Lou** in Nanxi (Figs. 46 and 47). Minoru's notes state it is supposed to be "earthquake proof", having survived an 6.2 earthquake in 1918 (Ref. 7, 11). It was built in 1693. Its diameter is 41.2 m, height is 4 stories, 21 families live there now, and there are 110 rooms. As can be seen in Figs. 46 and 47, the self-healing crack(s), do not seem very dramatic now. It seems more of a footnote. However, other cracks seem to have been filled, as can be seen in the photographs upon more detained study. Ref. 10 suggests that the "self-healing" phenomenon was effected by [at least in part] after shocks. This obviously needs a bit more investigation. Minoru, who is an engineer, suggests that he contact one of his professors, a seismic expert. Ref. 12).
- 9) **Answer #9**: "I assume they are all popular tourist sites." After visiting ~60 Hakka villages in Fujian and Guangdong provinces, it is clear that Hakka villages are not popular tourist sites, so far. I was amazed how few people, even Chinese, appreciate their own architectural heritage, especially achievements so extraordinary. They have powerful lessons for the present and future generations, many hundreds of years later. We hope that your research and our studies will help to change that, and thereby save many more tulous from being abandoned and ruined forever (Figs. 50, 51).

## **C) Structural Focus:**

- 1) **Specific Recommendation #1:** I recommend a focus on 4 different parameters of the external load bearing walls as a start, consisting of the rammed earth walls (pisé), and the stone foundation below it (Figs. 3, 4, 7-10, 11-17, 18-37, 46-51, 56-61, 101) for the current structural analysis, as the foundation to your study and future expansion of the project: greatest gain for smallest pain, optimizing visibility, marketability & future research.
  - a) with and without stone floors, to compare 2 very different dead loads (Figs. 52 to 55). This would increase the dead load per floor by an estimated ~15 PSF.
  - b) with and without reinforcing to compare 2 very different approaches to earthquake performance (Figs. 46 and 47)
  - c) additives: to establish the efficacy of natural bonding agents such as red sugar and glutinous rice that were traditionally mixed with the earth to make the wall stronger (Figs. 5 and 6, Refs. 9 and 11). [i.e. 沙 (sand), 黄土 (yellow soil), 红土 (red soil), 石灰 (lime), 红塘 (red sugar) and 糯米 (glutinous rice)], This will be of great interest to the **green** building movement.
  - d) compressive strength: initial testing. (i.e 250-500 PSI (Refs. 19-21), vs. 2600-3000 PSI for concrete) and to answer the question does rammed earth become harder with time? This would be of great interest to **green** professionals and government.

In the **future**, other less high profile parameters that can be analyzed include:

- e) interior wooden structure: including the racking strength or role of stairs in certain tulous. There are some tulous where structural issues are obvious, but not related to pisé. They were related to the wood structure, as can be seen in the photo of Yuchang that you attached from Ref. 8a
- f) lintels: including thicknesses, and length to dissipate vertical loads (Figs. 31, 35, 56 and 57)
- g) roofs: including roof overhangs and roof structure (Figs. 23, 58, 59 and 62, 63)
- h) outside veneer (parging): to protect walls against erosion (Figs. 18, 19, 22, 26-31) and to maintain structural integrity. This has been a universal failure and its solution would be a major breakthrough and a significant contribution to all 46 Hakka World Heritage Sites.
- i) survey of cracked walls to establish whether or not there is any reality to “self-healing” in cracks resulting from earthquakes as in Huanji Lou (Figs. 46 and 47).

Note: A section of a wall shows an outward slope, contrary to structural expectation. The exterior walls are tapered toward the outside rather than toward the inside (Figs. 35 and 44), indicating a buttressing effect to internal lateral loads (i.e outward pressures?), without any apparent justification, especially since it seriously compromises ground moisture protection and hurricane loads. Normally the buttress would be on the inside against an attack or wind loading from the outside and for rain protection. This seems to be a controversial paradox and a perplexing variation from standard engineering.

Another structural element you may wish to consider is the roof overhangs (Figs. 23, 58 to 61), and the roof structure (Figs. 62 and 63), since they are quite long and do carry a certain dead load, and on occasion, perhaps a live load, if it ever snows in this part of Fujian (interviews would establish if it ever snows).

In the future, other parameters that can be compared including: new vs. old buildings, high vs. low, different orientation (south facing walls may have higher temperatures), buildings with more or less **firewalls** (Figs. 64 and 65) differs greatly. The most frequent number was 8 (slide 37, Ref. 2).



## **D) Monitoring:**

- 1) **Specific Recommendation #2:** Hioki data loggers be considered for installation in several tulous for on-going year round temperature and humidity measurements.
  - 1) please see Figs. 66 And 67 for Hioki temperature/humidity **data loggers** that we have been using for several years. They run for a year before being downloaded. May I suggest these be considered for interior and exterior monitoring year round. It is critical to go beyond spot temperature readings.
  - 2) please the **graphs** generated from the data (Fig. 68 and 69). Minoru is in charge of monitoring. He could be very useful for on-site monitoring and measurements.
  - 3) please see Ref. 22 for an excellent paper on a thermal study on Cave Dwellings in China, which may have relevance in your work, especially slides 15 and 16.

Horizontal and vertical location of **sensors** relative to wall height (V), building floor (i.e. story, V), building room (H), will take some on-site discussion, due to effect of "interior courtyards" technically being exterior spaces when considering temperatures.

Minoru and I have also done **laser** measurements on some of the tulous.

One thing we have learned about **thermography** (IRT) is that calibration is absolutely critical as factory settings can seriously be off base, based on our experience. Testing and adjustment for calibration on-site, is critical in my estimation. The camera that Dr. Dieter Rempel has been using to do our thermography as shown in Figs. 70 and 71.

Moisture levels in walls may be important. Figs. 72 and 73 shows a **Temperature/Moisture probe** that we have used to determine moisture levels in mass and in walls. It is possible that hardness changes with moisture levels.

## **E) Comments on & Additions to Plan of Field Study:**

The *Plan of Field Study* does not yet indicate personnel, their roles or budgets. Any budget allocated towards ASH would be used for 3 personnel: Helen, Yan, Minoru (if available) and myself.

Perhaps the study title that now exclusively mentions "structural" investigations in the *Plan of Field Study* should be changed to reflect the **thermal, humidity** (and **sustainable**) investigations, as indicated in s. 1.2, to make it more marketable to the public and worthwhile for government funding.

## **F) Mass: addition to Plan of Field Study:**

- 1) **Specific Recommendation #3:** It would very useful to determine approximate total mass in tonnes, from which a **Building Time Constant** (Ref. 23, slides 11, 13, 14) could be calculated. This is a very important concept and index of building energy performance directly useful to modern engineering to determine thermal decay of a building. It is critical for the survival of a building's plumbing and mechanical system in times of power outages, especially during winter months. Mass on this scale also has a major effect on human comfort, especially in the winter time, as we will see in the Hakka buildings, if the inhabitants are surveyed.

### **G) Wall Construction:**

- 1) **Specific Recommendation #4:** It would be ideal if we could find any **rammed earth** wall under construction in China at the time of your trip. This would be a major breakthrough if one can be found. I am sure there are some under construction in various parts of China, but whether in the Yongding area specifically, is the question and challenge. However, Yan is a quite a sleuth and has been very useful to track illusive things down in China in the past. She is our best resource for such an undertaking. Because this takes time, I would like to get her going on this right away.

Some of our own past work with rammed earth is show in Figs. 74 to 83, and slide 34, in Ref. 2.

### **H) Alliances & Partners: addition to *Plan of Field Study***

- 1) **Specific Recommendation #5:** I strongly recommend collaboration with the **Hakka Research Institute** in Meizhou, through Prof. Fang (Figs. 89, 90) and some of his graduate students (see below) to utilize the resources of Jiaying University as previously noted in my email dated April 10,2009.
  - a) Prof. Fang: "房學嘉 Prof. 房學嘉" <[fangxj@jyu.edu.cn](mailto:fangxj@jyu.edu.cn)>, Xuejia <[yangshang21@hotmail.com](mailto:yangshang21@hotmail.com)>
  - b) Graduate student: "Xia (Ming) Yuanming" <[xym77@163.com](mailto:xym77@163.com)> (Figs. 91, 104)
- 2) **Specific Recommendation #6:** Alliances with international rammed earth organizations and suppliers are strongly recommended to promote our study, to increase the authority, credibility and impact of the findings, and for future funding opportunities.

### **I) People (ASH team members):** Jorg/Helen Ostrowski, Yan Xiaoyan, Minoru Ueda

- 1) **Specific Recommendation #7:** That Xiaoyan Yan-Li and Minoru Ueda be on our team.
  - a) **Xiaoyan Yan-Li** (Figs. 86, 88, 89, 94, 96-101) can help make arrangements and give the "local tour" (p. 3), as she has done for us in the past. She may also be useful in the noted "previsit study" (p. 3) and to arrange local workers for core extraction (p. 3). She is a good interpreter, whether verbal or written. She is Hakka and knows the Hakka dialect, which has facilitated our relationships with local people tremendously. She has been to Yongding area about 4 times, visiting tulous and with good contacts in local government, as previously noted in my emails of April 2 and 10, 2009 (attached). She is part of our study team in the work we have done, and our representative in China. She is gifted with people. She has given 3 presentations with us, including the World Hakka Conference in Xi'an (Fig. 94) and 2 presentations at the Hakka Research Institute, Jiaying University in Meizhou (Fig. 88) in October 2008. She is more familiar than any of us with Hakka buildings visited. She is familiar with sustainable principles, having recently graduated with a M. Sc. (International Tourism Management). Her dissertation was on Hakka EcoTourism. She is also familiar with our work. An asset of this calibre should be put to work for common benefit. I would highly recommend that you allow us to integrate her services, within our budget allowances.
  - b) **Minoru Ueda** (Figs. 36, 95-101) is an architect and structural engineer in Japan. He is also my colleague in Canada working with us on some of our projects as time permits. He lives in a sustainable home/office in Tokyo, complete with a grid connected PV system. He teaches at a university in Tokyo. He is very well informed on Japanese literature and research on Hakka buildings. He and Yan planned our trip through Yongding in April 2007 under my guidance, after I had done the preliminary work. He has a video camera, monitoring equipment, and laser measuring instrument, already used for our Hakka tulou research. Minoru and I have created an on-going spreadsheet with about 53 Hakka buildings in Fujian and Guangdong, listing various parameters such as: location, contact, remarks, materials, shape, year of construction, stories, height, area, diameter, # of rooms and present owners. May I suggest that this format and some of the content, and a survey sheet, would be very useful for this study, if we can integrate his service, skills and talent as our team member.



## **J) Architecture:**

- 1) **Specific Recommendation #8:** It is recommended that the final report include a section on the architectural evolution of tulous. This will provide the historical understanding of the development of various styles as depicted in Ref. 2, slides 29, 30-34. It will also enhance the promotion of the report, increase opportunities for further research and make the work relevant to a far greater audience than to a restricted and a narrow group of structural and material engineers and academics. Minoru knowledge, skill, work and contacts would be critical for this assignment.

## **K) History & Culture:**

- 1) **Specific Recommendation #9:** It is also recommended that the final report include a section on the history and culture of the Hakka people. Such an overview would provide an etymological context of the work to identify and explain its roots in the past, show its relevance to the future by empirical data of the present. This will again greatly amplify the report's relevance to people beyond the narrow band of scientists. This may also enhance possibilities of alliances and partnerships, especially provincial governments of Fujian, Guangdong, Jiangxi, Henan, and Shanxi. Yan could help on this assignment.

## **L) Sustainability:**

- 1) **Specific Recommendation #10:** I recommend that you try to address several key sustainable aspects of Hakka Tulous, as feasible, so that it has far greater appeal, marketability and impact, especially to funding organizations, university courses, Chinese Government agencies (local, provincial and national), the general public, media and the rapidly expanding **green building community**. You have already started by introducing such topics as comfort and durability (s. 2). Durability is the key to sustainability. Rammed earth structures certainly have durability. The ecological footprint of a tulou should be calculated. The ecological footprint of the Arab countries by comparison is 11.9 (Ref. 15), the US is 9.6 (Ref. 15), Canada is 7.1 (Ref. 16), Calgary is 9.9 (Ref. 16), China is 1.6 ha/person (Ref. 14). My guesstimate for the **tulou** dwellers would be 0.8 ha/person. The biocapacity of planet earth is 1.8 ha/person. (Refs. 15, 16). Such a low ecological footprint for the tulous is worthy of an international environmental award, if verified.

## **M) Archives & Interviews:**

In early April 2007, both Helen and Yan did a lot of interviewing of tulou dwellers to find out the lowest **temperatures** in the middle of winter. They learned that tulous reached temperatures of 5-7 °C. The tulou mass in the winter months was a major liability from a comfort point of view, as we also know from our own projects in Canada.

In October 2008, we learned that clan archives are the best source of information on dates, names and events, as seen in Figs. 102 to 105. They are readily available, well kept, accurate and people are eager to share them with researchers. They provide the historical context for the village or home-town and your research. They are indispensable in their value. They can save a lot of time and effort, gossip and guesswork. Such requests also build alliances and rapport with the local people and village elders, another task that Yan excelled in. The importance cannot be overemphasized.

- 1) **Specific Recommendation #11:** I strongly recommend that all structural research be augmented by on-site personal interviews using survey forms and clan archives, when ever possible to reinforce your study with this technique of information gathering. This is simultaneously an opportunity to enhance community relations and lubricate on-site work. I further recommend that Yan be responsible for this aspect of the research.

## **N) Proposal**

- 1) **Specific Recommendation #12:** It may be feasible, that if and as this research widens and becomes more inclusive and holistic, it may lead to one of the Hakka tulous being selected as a new Centre for Sustainable Living or Building Materials or the **World Centre for Rammed Earth Design and Construction**, if worthy of our recommendation. Your research and multi-lingual collaboration with researchers in different countries could justify such an idea and followup program, especially if partnered with 2 research universities (Hakka Research Institute at Jiaying University and the one of the academic institutions listed in Ref. 18. This is a unique place on earth, with such an important and recognized and inventory of diverse rammed earth buildings, depository of living examples. It would also help to bring more researchers and ecotourist to the Yongding area, and in the process, help to protect and preserve more buildings, culture and history of the Hakka people.

## **O) Photos:**

- 1) my photos sent on April 10, 2009 are now labelled below as requested.
- 1) Fig. 03 (above): photo of rammed earth walls under construction (Zhenfu Lou museum)
  - 2) Fig. 07 (above): End of Wood with wood branch reinforcing sticking out
  - 3) Fig. 09 (above): Rammed Earth Wall (Jiusheng Lou, Hongkeng): erosion from faulty roof, showing wood branches as reinforcing
  - 4) Fig. 33 (above): Helen measuring thickness of rammed earth wall (Fuxing Lou, Hulei town)
  - 5) Fig. 34 (above): measuring tape showing 4'-0" wall thickness
  - 6) Fig. 57 (above): Rammed Earth Wall (Rulindi Lou, GaoBei Village) showing wide wood lintels
  - 7) Fig. 106 (below): Foundation parging: (Yuchang Lou, Hongkeng)
  - 8) Fig. 107 (below): Yanlin Lou, Hongkeng ("Fortress" style, slide 34, Ref. 2)
  - 9) Fig. 109 (below): Rammed Earth Wall (Yuan Yuan Lou, Meizhou) showing scale of wall (~9 m)
  - 10) Fig. 108 (below): Rammed Earth Wall (Yuan Yuan Lou) showing crack and no wood reinforcing





## **P) Bibliography:**

- 01) China Dwellings: <http://www.chinadwelling.dk/pdf/kinakort.PDF>
- 02) *Fujian Hakka Tulou 2007 Odyssey*:  
<http://www3.telus.net/mudesign/Hakka/Hakka01.html>  
Click on: *UN World Heritage 2008 Fujina Tolou*  
Hongkeng: slides 5, 6, 12; Fuyu: 15, 16 & 33; Fuxing 26; Yuchang 35; Chengqi: 5 (#28), 17, 18
- 03) Minoru Ueda, *Hakka Tulou Inventory List*, 2007-2008
- 04) *Plans to Protect Hakka Villages*:  
<http://www.ecobuildings.net/pdfs/Hakka%20World%20Conference.pdf>
- 05) *Fujian Earth Building (Tulou)-Chengqilou*,  
<http://www.discoverfujian.com/TulouHighlights-1.asp?id=30>
- 06) Chinese web sites: *Earth Buildings*, <http://www.ydtu.com/> and <http://www.fjtl.gov.cn/>
- 07) *Earthen Houses (Tulou), Fujian Province*, <http://www.icm.gov.mo/exhibition/tc/fjintroE.asp>  
Hekeng Tulou: Located in Hekeng Village, Shuyang Town, this extremely extensive and impressive cluster consists of 27 earthen houses.  
Huanjilou was built in 1693, .... In 1918 it withstood an earthquake measuring 6.2 on the Richter scale ...
- 08) *Yuchang lou*: a) [http://commons.wikimedia.org/wiki/File:Yuchang\\_lou\\_interior.JPG](http://commons.wikimedia.org/wiki/File:Yuchang_lou_interior.JPG)  
also Eyri Lou b) [http://en.wikipedia.org/wiki/Fujian\\_Tulou](http://en.wikipedia.org/wiki/Fujian_Tulou)
- 09) *Tulou: The Earthen Architecture of Fujian's Mountain Villages*,  
[http://www.chinatoday.com.cn/ctenglish/se/txt/2009-01/15/content\\_174824.htm](http://www.chinatoday.com.cn/ctenglish/se/txt/2009-01/15/content_174824.htm)  
Sishi Hall, a combination of ancestral memorial hall and private school, in the center of **Huaiyuan** Lou.

Raw materials for the tulou were obtained locally. The principal building material was a mixture of clay, sand, lime and water, and egg whites, brown sugar and rice water were added as adhesive agents. It was then rammed to form the walls. Once they dried, the walls were so hard that driving a nail into them would have been difficult. As a local saying said: "One bowl of earth equals a bowl of pork." Fir branches, which are extremely sturdy and do not rot, were used as reinforcements, and many centuries later they have remained intact.

Tulous are located in a region prone to frequent earthquakes, and their circular construction helps them withstand the regular shocks. The **Huanji** Lou in Yongding County, for example, experienced a strong earthquake in 1918, which left a crack three meters long and 20 centimeters wide. But not long after the quake, the seam closed, leaving only a hairline fracture.

One exceptional example is **Yuchang** Lou, in Nanjing County, which remains sturdy despite the ravages of time. Built 700 years ago, not a single pillar supporting the building remains straight, and all the wooden structures lean left or right, with the largest inclination reaching 15 degrees. It looks as if it would collapse with a gust of wind, and visitors usually walk with the greatest of care. Locals are more accustomed, and walk with ease.

According to 55-year-old Liu Chunwei, the current owner of the compound, the inclination is due to the deviation between the footing of the wall and the wooden structures. The wall is 18 meters tall, and tapers from its base to the top, but the wooden structures do not taper. As a result, all the pillars are inclined. Nevertheless, the pillars on top and those on the first floor are lined up along the same axis, without any shifting of the center of gravity, much like a stack of chairs in an acrobatic display – even though the chairs are piled up one upon the other in different directions, the center of gravity remains constant.

Yuchang Lou has been able to stand for more than 700 years because of its thick walls of rammed earth, which support the building's main weight, while the pillars only support the floorboard. After visiting Yuchang Lou, an Italian expert commented that the 700-year-old structure was a miracle of engineering.

10) Fujian Tulou, [http://en.wikipedia.org/wiki/Fujian\\_Tulou#Yuchang\\_lou](http://en.wikipedia.org/wiki/Fujian_Tulou#Yuchang_lou)

**Yuchanglou** 裕昌楼 is a five-story tulou located at Nangjing county Shuyang district Xiabianliao village.

It was built in 1308 [Yuan dynasty](#) by the Liu family clan. It is one of the oldest and tallest tulou in China. Yuchanglou has been nicknamed the "zigzag building", because the vertical wooden post structure is not straight and perpendicular, but zigzags left and right. It was built that way due to an error measuring the building materials. But in spite of this apparent infirmity, this tall tulou withstood 700 hundred years of natural elements and social turmoil. Yuchanglou's outer ring is 36 m in diameter and boasts five stories, with 50 rooms on each floor.

Each of the 25 kitchens on the ground floor at the back half of the circle has a private water well beside its stove. This is the only tulou in all Fujian with such convenient water supply.

There was a one story inner-ring house surrounding the ancestral hall as late as 2003. This part of the building stood nearly 700 hundred years intact until, unfortunately, it was dismantled after 2003

11) *The Myths and Secret of Hakka Round Houses or Tulou*,  
[http://www.whatsonxiamen.com/news\\_msg.php?titleid=3866](http://www.whatsonxiamen.com/news_msg.php?titleid=3866)

Myth 2: Tulou are built with a mix of brown sugar water and glutinous rice.

... the walls are made of pounded red clay dug from beneath the irrigated fields. Their strength comes from the consistency of the clay, not a hardened mixture of sweets. The clay should form a ball when squeezed. According to Lin, a waterlogged mix will expand, while too much sand can make it dry and brittle, so bamboo chips and small stones are used for reinforcement. Learning the process from various masters, Lin had worked as a builder for more than ten years.

The rice and sugar myth stems from a tulou-building tradition. Before the villagers begin their work, the clan commissioning the construction invites them to eat "ci ba", or glutinous rice balls stuffed with a sweet filling. Says Lin: "If the family cannot provide 'ci ba', the builders joke that they will do a shoddy job."

Myth 3: A 20x300 cm crack in the wall of **Huanji** tulou healed itself.

In 1918, a magnitude-6.22 quake shook Yongding county, creating a massive crack in the Huanji building. The wall seemed to repair itself though, and only a trace of it is visible in the tan-colored wall today, earning Huanji the nickname of "most mysterious" tulou.

Edged by a seismically active belt, Fujian's Hakka people learned to build their tulou accordingly. Quake resistance depends on shape, says 86-year-old Shu Guanghua. The concentric walls are slightly wider and thicker at the bottom than the top, tapering from 1.2 to 0.9 m.



When shaken, the building collapses inward, packing the structure even more tightly. While the initial quake had been strong enough to crack the Huanji building, subsequent aftershocks actually helped close the gap.

12) email from Minoru Ueda, on May 1, 2009:

Jorg: I am not sure for the "self-healing" story but engineering point of view, I also think it is unique. Maybe sometime we may discuss with Verlin and my old boss who is the seismic specialist. Minoru

13) China's 1.3 billion residents leave smaller ecological footprint, Sept. 24, 2006,

<http://www.heraldtribune.com/article/20060924/COLUMNIST18/609240431>

"The average ecological footprint for one Chinese citizen calculated in 2006 is 2.0 (meaning that it takes two global acres of resources to sustain each individual). The average footprint in Beijing is 6.2, indicating that urban residents consume more energy than rural dwellers. In contrast, the average ecological footprint of an American is 24, although slightly less in Sarasota, at 22.2. (Reported on July 20, 2004, by Redefining Progress of Oakland, Calif.). The average American currently uses more than 10 times more resources than the average Chinese person."

14) CCICED - WWF, *Report on Ecological Footprint in China*,

<http://www.footprintnetwork.org/download.php?id=503>

Focusing on individual lifestyle, China's Ecological Footprint in 2003 was 1.6 global hectares per person, the 69th highest country in the world, and lower than the world average Ecological Footprint of 2.2 global hectares per person."

15) *The average United Arab Emirates citizen had the greatest ecological footprint in 2003 at 11.9 global hectares each; compare to US at 9.6 (2nd), Canada at 7.6 (5th), Australia at 6.4 (6th), UK at 5.6 (14th), China at 1.6 (69th) and India at 0.8 (125th) versus the world mean at 2.2 and biocapacity at 1.8*, October 23, 2007

<http://envirostats.digitalcitizen.ca/2007/10/23/0509/>

16) Marian Scott, Canada among world's largest consumers, Calgary's footprint highest in nation, Canwest News Service, March 28, 2009

<http://www.vancouversun.com/Technology/Canada+among+world+largest+consumers/1438843/story.html>

According to the World Wildlife Fund's 2008 Living Planet Report, Canadians' average footprint is 7.1 global hectares.

The Earth's carrying capacity is 1.8 hectares per person, meaning we are in "overshoot"--spending the Earth's natural capital at a pace that threatens our very survival. The average global footprint is 2.7 hectares.

The footprints of Canadian cities range from a high of 9.9 for Calgary

17) *Living Planet 2008 Report*, Global hectares per person, Total Ecological Footprint, China: 2.1 (p. 34), Canada: 7.1, US: 9.4 (p. 36)

18) *Hakka academic institutions*,

<http://www.hakka.gov.tw/lp.asp?ctNode=908&CtUnit=400&BaseDSD=7&mp=208&ps=>

- 19) *IS RAMMED EARTH A DIY (DO IT YOURSELF) WAY TO BUILD?*,  
<http://www.sirewall.com/wp-content/themes/sirewall/pdf/diy-sirewall.pdf>  
Note: This biased article shows 250 PSI for traditional rammed earth walls, where clay is the binder and various compressive loads at various thicknesses.
- 20) *3.0 Soils for Rammed Earth, Caliche Block, and Soil Material Construction*,  
<http://www.greenbuilder.com/sourcebook/EarthGuidelines.html>  
Rammed earth walls have been tested with a compressive strength of 30 to 90 psi immediately after forming. Ultimate compressive strength should reach 450-800 psi.
- 21) *Credentials: Research & Development - The SIREWALL™ Story*,  
<http://www.terrafirmabuilders.ca/Credentials/RandD.html>  
1994 Concurrent Testing
- The engineers took core samples and tested the pull-out strength of the bamboo. It was easily strong enough and showed how ductile the rammed earth was. It was approved. However, over time, Meror noticed that the bamboo tended to separate from the earth. It was suspected this had to do with the moisture variations in the bamboo, so they returned to steel reinforcing.
- 22) Toshiyuki Watanabe, Chair, *Project on "Study of Energy Consumption and Indoor Environment Problems of Residential Buildings in China"*, Research Committee of Architectural Institute of Japan, <http://news-sv.aij.or.jp/t300/HP/English3.pdf>
- 23) Kumar Mithraratne, Brenda Vale, *Thermal Characteristics of High Thermal Mass Passive Solar Houses*, University of Auckland, NZ, July 2004