



# Mise en place du laboratoire de la construction durable et de la pédagogie “ architecture de terre ” à l’École d’architecture de l’Académie d’art de Chine

Wen Zhang

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ECOLE NATIONALE SUPERIEURE D'ARCHITECTURE DE GRENOBLE

Mémoire du  
Diplôme de Spécialisation et d'Approfondissement – Architecture de Terre  
Mention Patrimoine  
DSA-Terre 2010 - 2012



MISE EN PLACE DU LABORATOIRE DE LA CONSTRUCTION DURABLE ET DE LA PÉDAGOGIE « ARCHITECTURE DE TERRE » À L'ÉCOLE D'ARCHITECTURE DE L'ACADÉMIE D'ART DE CHINE

ZHANG Wen  
Architecte  
Juin 2012

Ministère de la Culture et de la Communication  
Direction générale des patrimoines



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Mémoire de DSA

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TERRE » À L'ÉCOLE D'ARCHITECTURE DE L'ACADÉMIE D'ART DE CHINE

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## Résumé

Le mémoire retrace le processus de mise en place du Laboratoire de la Construction Durable à l'École d'Architecture de l'Académie d'Art de Chine. Il introduit d'abord l'intention initiale de la mise en place du LCD et le contexte dans lequel il s'inscrit ; puis décrit son processus de mise en place, qui a été élaboré selon trois aspects comprenant l'installation spatiale du laboratoire, l'installation des outils et équipements et de la formation du personnel du laboratoire. Il conclut en décrivant les expériences et enseignements issus de ce processus.

Ce mémoire décrit aussi la pédagogie « terre » mise en place à l'École d'Architecture. Jusqu'alors, trois cours ont été dispensés. Chaque cours a fait face à différents problèmes dépendant de leurs contextes. Ce mémoire participe de l'élaboration des objectifs pédagogiques, du processus d'enseignement et des effets et expériences attendus pour chaque cours. L'expérience acquise lors des deux premiers cours ont permis d'améliorer l'enseignement dispensé pendant le troisième cours.

Outre l'expérience acquise pendant les cours, ce mémoire décrit aussi le travail de relevé sur l'habitat vernaculaire Chinois, l'expérience lors de différents workshops et projets menés utilisant la technique du pisé et les problèmes qui en ont découlé reflétant la situation actuelle de l'Architecture de terre en Chine.

Dans la partie de la conclusion, l'auteur a examiné le potentiel de développement de l'architecture de terre en Chine en se basant sur l'observation de l'architecture de terre lors de son séjour à Grenoble ainsi que sur des échanges et conversations avec différents acteurs de la construction en terre qu'elle a pu rencontrer.

Enfin, l'auteur examine le développement de son plan de carrière afin de pouvoir mieux contribuer à la recherche sur l'architecture de terre crue.

# 中国美术学院可持续建造实验室建设及夯土教学的研究

## 摘 要

本文记述了中国美术学院建筑艺术学院可持续建造实验室的建设过程，首先对成立该实验室的背景和目的做一简单的介绍，然后较为详细地叙述了实验室的建设过程。这一过程主要从实验室的场地改造和布置、工具设备的配置以及实验室工作人员的培训三个方面进行阐述，并结合建设过程中遇到的问题进行相应的经验和教训的总结。

此外，本文还记述了我院开展夯土建造课程的情况。迄今为止共开展了三次夯土建造课程，每次课程在当时的条件下面临不同的问题，主要从每一次课程的教学目的、教学情况、教学成效及经验总结三个方面来阐述。其中，前两次课程对学生进行了学习效果的调查反馈，第三次课程则是在以往教学的经验教训总结以及学生的调查反馈的基础上，进行有针对性的教学改进。

在实验课程之外，记述了本人近年来参与的生土民居考察、夯土工作营和夯土工程等生土工作中遇到的一系列问题，反应出我国生土建筑的现状。

在论文的结语部分，结合本人在法留学期间关于生土建筑的考察，以及本人在生土工作期间与相关的各界人士的交流，展望我国生土建筑的未來及其可能的发展方向。结语的最后将谈及我个人在生土建筑方面的职业发展计划，以期为生土事业尽一份薄力。

# **A Research on the Establishment of Sustainable Construction Laboratory of CAA and Teaching on Rammed Earth**

## **Abstract**

The thesis recorded the establishing process of the Sustainable Construction Laboratory in Architecture School, China Academy of Art. It first introduced the background and purpose of establishing SCL; then depicted the establishing process, which was elaborated from three aspects including the lab site renovation and layout, tool and facility disposition and training of the staff and concluded the experience and lesson gained from the process.

Besides, the thesis also described the rammed earth construction courses implemented in the school. Till now there have been three such courses. Every course faced with different problems to that context. The thesis elaborated the teaching objectives, teaching process as well as the effect and experience of each course, among which the first two courses made feedback survey on the learning effect and the third course was based on the previous experience and feedback from the students, improving teaching accordingly.

In addition to the experimental courses, the thesis has also recorded the field surveys of earth folk houses, rammed earth workshops and rammed earth projects experienced by the author and the serial problems emerged from these work, which reflect the current condition of earth architecture in China.

In the conclusion part, the author looked into the future of the Chinese earth architecture and its possible development direction based on her investigations on earth architecture during the training program in France as well as the exchanges and communication with people of various areas relating to earth architecture in her work on earth. In the end, the author discussed her future professional development plan on earth architecture in order to contribute more to the earth research.



# 目录

<b>1 前言</b>	<b>10</b>
<b>1.1 实验室成立的背景</b>	<b>10</b>
1.1.1 建筑艺术学院的学术指向	10
1.1.2 浙江省乃至我国的生土民居	12
1.1.3 王澍教授的夯土实践	14
<b>1.2 实验室建设的目的</b>	<b>18</b>
1.2.1 课程教学	18
1.2.2 课题研究	18
1.2.3 工程实践	18
<b>1.3 实验室建设的途径</b>	<b>20</b>
<b>2 实验室建设</b>	<b>22</b>
<b>2.1 实验室的选址与改建</b>	<b>24</b>
<b>2.2 生土材料分析实验室</b>	<b>24</b>
2.2.1 实验室的布局	24
2.2.2 设备工具的配置	24
<b>2.3 建造工作坊</b>	<b>26</b>
2.3.1 工作场地的布置	26
2.3.2 工具设备的配置	26
<b>2.4 实验室人员培训</b>	<b>30</b>
2.4.1 培训对象和目的	32
2.4.2 培训时间和内容	32
<b>2.5 实验室建设的经验总结</b>	<b>34</b>
<b>3 夯土教学</b>	<b>40</b>
<b>3.1 第一次夯土建造课程</b>	<b>40</b>
3.1.1 教学目的与内容	40
3.1.2 课程计划与实施	42
3.1.3 教学成效与经验	44
<b>3.2 第二次夯土建造课程</b>	<b>48</b>
3.2.1 课程原计划	48
3.2.2 实际的教学过程	48
3.2.3 教学成效与经验	52
<b>3.3 教学反馈</b>	<b>56</b>
<b>3.4 第三次夯土建造课程</b>	<b>58</b>
3.4.1 课程任务	60
3.4.2 课程安排	60
3.4.3 教学成效与经验	64
<b>4 中国生土建筑现状调查</b>	<b>68</b>
<b>4.1 生土民居考察</b>	<b>68</b>
<b>4.2 夯土工作营考察</b>	<b>72</b>
<b>4.3 夯土工程考察</b>	<b>74</b>
<b>5 结语</b>	<b>82</b>
5.1 中国当代生土建筑发展方向的探讨	82
5.2 个人今后的生土工作计划	90
附录	92
参考文献	102
后记	104

# Content

<b>1 Introduction</b>	<b>11</b>
<b>1.1 Background of the Establishment of SCL</b>	11
1.1.1 Academic direction of Architecture School of CAA	11
1.1.2 Earth folk houses in Zhejiang and China	13
1.1.3 Rammed earth practice of Professor Wang Shu	15
<b>1.2 Objectives of SCL</b>	19
1.2.1 Curriculum teaching	19
1.2.2 Research project	19
1.2.3 Project practice	21
<b>1.3 Approach of the establishment of SCL</b>	21
<b>2 Establishment of SCL</b>	<b>23</b>
<b>2.1 Space reconstruction</b>	25
<b>2.2 Material Analysis Laboratory</b>	25
2.2.1 Layout of the laboratory	27
2.2.2 Equipment and tools of the laboratory	27
<b>2.3 Construction Workshop</b>	27
2.3.1 Layout of working space	29
2.3.2 Equipment and tools of the workshop	29
<b>2.4 Personnel Training</b>	33
2.4.1 Trainees and training objectives	35
2.4.2 Training process	35
<b>2.5 Experience summary</b>	37
<b>3 Teaching on rammed earth</b>	<b>41</b>
<b>3.1 Rammed earth course 1</b>	41
3.1.1 Objective and content	41
3.1.2 Teaching plan and process	41
3.1.3 Effect and experience	45
<b>3.2 Rammed earth course 2</b>	47
3.2.1 the original plan	47
3.2.2 Course process	49
3.2.3 Effect and experience	51
<b>3.3 Feedback</b>	55
<b>3.4 Rammed earth course 3</b>	57
3.4.1 Task	59
3.4.2 Arrangement of the course	59
3.4.3 Effect and experience	65
<b>4 Investigations on the current condition of earth architecture in China</b>	<b>69</b>
<b>4.1 Survey of the earth folk houses</b>	69
<b>4.2 Survey of rammed earth workshop</b>	73
<b>4.3 Survey of rammed earth projects</b>	77
<b>5 Conclusion</b>	<b>83</b>
<b>5.1 Development direction of contemporary earth architecture in China</b>	83
<b>5.2 The plan on earth architecture for the future</b>	91
<b>Appendix</b>	<b>93</b>
<b>Reference</b>	<b>103</b>
<b>Postscript</b>	<b>105</b>

## 1 前言

此论文作为本人 DSA-Terre2010-2012 课程的毕业论文,记述了自 2011 年 9 月至 2012 年 6 月,本人在中国美术学院工作(亦为 DSA 课程的实习)期间,参加的与生土建筑有关的部分工作,主要包括两个方面:中国美术学院建筑艺术学院可持续建造实验室的建设和夯土建造的课程教学。

事实上,这两个方面是紧密关联的。建筑艺术学院建立可持续建造实验室的目的之一即是服务于课程教学。实验室从无到有,到逐步完善,使得我院的建造课程得以真正意义上地开展。而且,实验室将成为我院科研的国际交流平台,拓宽学术视野,促进更具创新性、更加有效的教学途径的探索。同时,实验室也会为满足日渐成熟的教学体系的教学需要而相应地调整发展方向。

因此,此文中将对我院可持续建造实验室建设和夯土建造教学进行较为详细的过程记录以及相应的经验总结。并在本人参与的一系列生土建筑工作和学习考察的基础上,展望我国生土建筑的发展。

### 1.1 实验室成立的背景

#### 1.1.1 建筑艺术学院的学术指向

中国美术学院建筑艺术学院从建立之初,就明确要重建一种当代中国本土的建筑学。建筑系的课程体系强调所有新建筑的创作都应以本土的历史根源为基础,强调现场的真实性和建构体系的真实性及本土生活的真实性。针对国内建筑院校,包括理工科院校在建筑的建构性实践上的缺陷,将专业课程全面改革为在实验室中的实践课程,立足于创建一种适用于艺术院校特点的建筑教学体系的探索。



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# 1 Introduction

As the thesis paper for the DSA-Terre2010-2012, it has recorded parts of my participation of the earth architecture during my working (also internship for DSA) in the Architecture School, China Academy of Art, which includes two aspects: the establishment of the Sustainable Construction Laboratory of the Architecture school, CAA and the teaching courses of the rammed earth construction.

In fact, they are two closely relative parts. One of the main objectives of the Sustainable Construction Lab is to serve for teaching. The lab was established from nothing, and then improved step by step. It has enabled the construction courses of the school to be implemented truly. What's more, the lab will become the international exchange platform for our school, which is to expand the academic scope of view, promote more innovative and effective teaching approaches. At the same time, the lab also needs to adjust development direction in order to meet the requirements of the increasingly developed teaching system.

Therefore, I have recorded in details of the process of the establishment of the Sustainable Construction Lab and the rammed earth course and the respective experience summary in this thesis. Besides, the thesis also looks into the future development of the earth architecture in China based on my working and study experience on it.

## 1.1 Background of the Establishment of SCL

### 1.1.1 Academic direction of Architecture School of CAA

From the establishment of the Architecture School, CAA, its statement is to re-establish a contemporary Chinese local architecture. The curriculum system of the Architecture Department emphasizes that the creation of new buildings should be based on the local historical roots. It has attached great importance to the reality of the site, the reality of the construction system and the reality of local life. Faced with the fact that domestic architecture schools, including the technology and engineering schools have a defect on the constructional practice in architecture, the Architecture School of CAA has made a revolution on curriculum to practice in the lab. It aims to create a teaching system of architectural design that is in accordance with the features of the arts educational institutes.

This academic pursuit of the school was initialed by its dean Prof. Wang Shu when the Architecture Department was set up. As the pioneer and leading role of “Experimental Architecture”—the most internationally influential architectural movement in nowadays China, Prof. Wang Shu leads the team to devote themselves to the efforts of re-establishment of a contemporary Chinese local and new architectural education system. The “experimental architectural” exploration that he insists especially emphasizes the sustainable construction technology combined with humane consideration. From 2009, he has been leading the teaching and research team to make a general research and survey of the local architectural resources in the province of Zhejiang. The goal is to establish a database for the local architectural resources of the province within four years, which is supposed to have the function of instructing directly the local construction and protection of the architectural resources in Zhejiang.

Hence, SCL emerged. It would be combined with the research on the local architectural construction system of Zhejiang Province, utilize modern technical means and protect, reproduce, re-excavate or even re-develop the local architectural materials and construction of Zhejiang.



建筑艺术学院的这一学术追求，是由院长王澍教授从建系伊始就提出的。作为“实验建筑”这一中国目前最具国际学术影响建筑运动的先驱者和领军人物，王澍教授一直带领学术梯队致力于重建一种当代中国本土的新建筑教育体系，其主张的“实验建筑”探索特别强调有效结合人文思考与可持续建造技术。自2009年以来，他带领教学研究团队，立足本土，展开浙江省乡土建筑资源普查，力争在四年内建立起浙江乡土建筑资源数据库，对浙江乡村建设和建筑资源保护起到直接指导作用。

由此，可持续建造实验室应运而生，它将与浙江省乡土建筑建造体系的研究相结合，借助现代技术手段，对浙江省乡土建筑材料及其建造进行保护、重现、再挖掘、以至再发展。

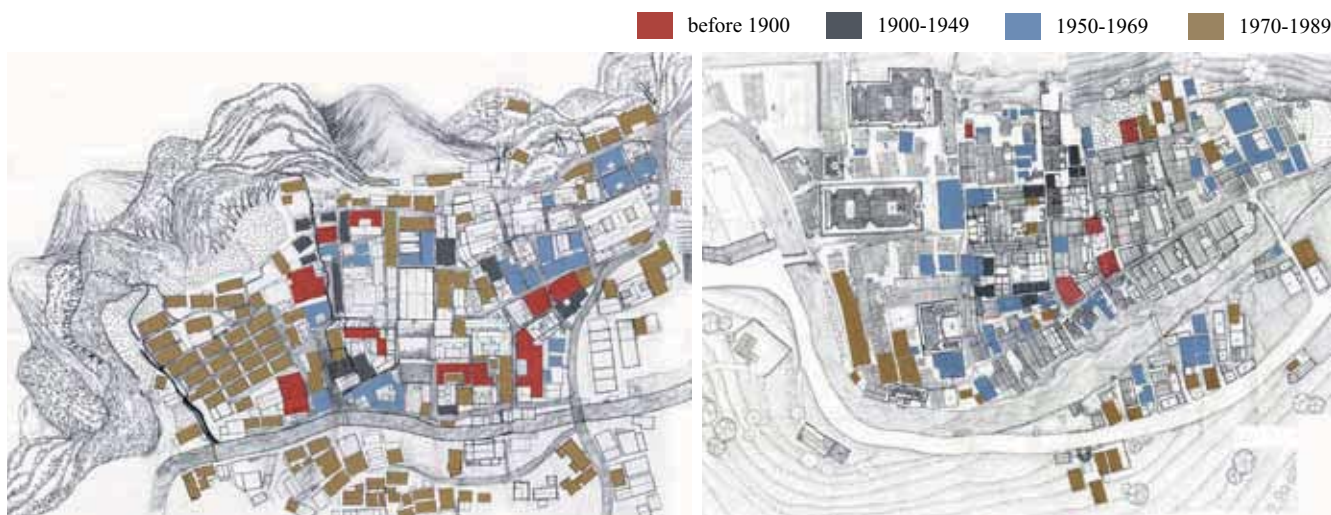
需要指出的是，可持续建造实验室建立之初的第一个重点研究对象定位为生土。这不仅是由生土材料本身的重要性，还因为以生土作为建造研究对象，也必将涉及生土建造过程中相关的一系列乡土材料的研究，如木、砖、石甚至竹等。

### 1.1.2 浙江省乃至我国的生土民居

众所周知，我国的生土民居分布广泛，而且建造方式多样。而中国美术学院所在的浙江省，也现存大量的夯土民居。在浙江省乡土建筑资源普查的过程中，生土民居及其村落亦作为普查重点。

2010年3月，我们考察了金华市武义县郭洞村。这里现存的夯土民居大致可以分为两个时期、两种建筑格局，一是民国乃至明清时期的传统民居，多为三合院形式；二是解放后六七十年代的新民居，多为一字型。从两种形式的夯土民居的地理分布，可以较为明显地看出民居形式的改变与村落发展变迁的关系。虽然建筑格局不同，但新老民居夯土材料的结构方式是相同的，即作为木框架结构的围护墙体，与木结构通过预埋于夯土墙内的木杆相连接。

在郭洞村西南方向的小山村山下鲍，与郭洞村同属一个地区，同样大量使用夯土作为主要的建筑材料。但由于其地理位置较为偏僻，交通不便，也因此更少受到现代城乡建设发展的影响，其村落格局、建筑格局和建筑质量的保存更为完整。同时，由于山下鲍的建筑依山势、水势而建，村落空间更加自由丰富，充分显示了传统民居自发建造的原生态特征。2012年4月，时隔两年，我院再次考察了该村，收集整理了大量的第一手资料。



郭洞村夯土民居分布图，左：郭上村，右：郭下村，金华市武义县，浙江

Rammed earth folk houses layout plan of Guodong, Left: Guoshang, Right: Guoxia, Wuyi, Jinhua, Zhejiang, 03/2010 (from Guodong village survey book)

It should be pointed out that the first research object after the establishment of the lab is earth. It is not just because of the importance of the earth material itself, but also because that used earth as the construction research object, it would definitely involve researches of a range of relative indigenous materials (such as wood, brick, stone or even bamboo) during the earth construction process.

### 1.1.2 Earth folk houses in Zhejiang and China

It is well known that earth folk houses are spread in many areas of China with diverse ways of construction. In Zhejiang Province, where China Academy of Art is located, a large amount of rammed earth houses exist. In the process of survey of the local architectural resources in Zhejiang, the earth folk houses are the important point.

In March 2010, we made survey of the Guodong village in county Wuyi, Jinhua. The existing earth folk houses could be mainly classified into two architectural patterns of two different ages: the houses dated back to the Republic of China or even Qing dynasty with a pattern of three-folded courtyard; the houses dated back to the 1960s and 1970s after the liberation with a pattern of linear. The geographical distribution of the two categories shows clearly the relationship between the changes of the patterns and the development of the village. Although the architectural pattern are different, the structures of the earth material of the old and new houses are similar, that is, the surrounding walls of wooden frame were connected with the wooden frames by the wooden sticks pre-embedded in the walls.

The small mountain village of Shanxiabao is located to the southwest of Guodong. The two villages are in the same area. There are also large amount of houses using rammed earth as the main architectural material. But since it is in the remote area and the transportation is inconvenient, it is less influenced by the modern development. The village layout, architectural patterns and architectural quality is preserved in a better condition. At the same time, the buildings of the village were constructed according to the winding of the hills and rivers, which made the space of the village more abundant and revealed fully of the original biological features of the autonomously built traditional residential houses. After two years in April 2012, our school made a further survey of this village again and accumulated a lot of direct materials.

In fact, from 2010 till now, since I started to devoting to the relative work of earth architecture, I have already taken field trips in areas of the provinces of Zhejiang, Fujian, Shanxi, Gansu and Yunnan



左：郭洞村传统三合院夯土民居；右：郭洞村近代的一字型民居

Left: Traditional folk house of Sanheyuan in Guodong; Right: Latter-day line-shaped folk house in Guodong, 03/2010



事实上，从 2010 年至今，自我从事与生土建筑相关的工作以来，已陆续考察了浙江省、福建省、山西省、甘肃省和云南省部分地区的生土民居。在考察中，不难看出各个地区使用生土方式的差异，大到生土的建造方式，有夯土、土坯、土窑和面层；再到生土材料的结构方式，承重的、非承重的；小到生土建造的构造方式，如夯土建造模板系统有板式、椽式等。可以看出，各地生土材料的使用方式恰是与当地的民居空间形式和结构形式相适应的，还与当地材料的特点相适应。

考察过程中，令人心痛的是，各地的生土民居都正在遭受或面临现代建造方式的冲击。除了人们对于“土房子”惯有的陈旧观念外，高质量的建造技术的欠缺同样是生土民居保存、修复和新建的障碍。因此，生土建筑、生土建造技术的科学和应用研究已是刻不容缓。

### 1.1.3 王澍教授的夯土实践

作为学院的本土建筑学学术方向的领导者，王澍教授早在 2000 年就对夯土进行了尝试，将其作为一次当代艺术展的雕塑作品。作为雕塑的夯土墙三个月之后就被拆除了，原因是主办方认为这是一个不美的作品，太“土”。王澍教授认为夯土墙这种“尘归尘、土归土”的结局也不违背夯土的使用意图，因为当时使用的土正是其他艺术家雕塑做基础时挖掘出来的土。但是，这件事说明了当时人们普遍对夯土这种乡土的做法在当代的使用还不能接受。2006 年，王澍教授在他建成的宁波五散房之一的茶室中，又一次使用夯土作为茶室的围护墙体。这一次夯土墙



左：山下鲍民居夯土墙与木结构的连接，浙江

Left: Connection between rammed earth walls and wooden structure of folk houses in Shanxiabao, Zhejiang, 03/2010

右：马岔村椽式模板夯土技术，甘肃

Right: Rafter pattern formwork in Macha, Gansu, 08/2011 (photography: Zhou Gongzhao)

and investigated the earth folk houses there. In the investigation, it was not difficult to judge the differences of the earth application methods between areas, from aspects from as big as the ways of construction including rammed earth, adobe, dugout earth and surface treatment and the structure patterns of the earth material including load-bearing or non-load-bearing, from as small as the structural ways of the earth construction, for example, the earth construction formwork system has plank pattern, rafter pattern etc. It could be seen that the application ways of the earth material in various areas are identical to the local residential space and structure forms as well as to the features of the local materials.

During the investigation process, it was painful to see the earth folk houses in those areas were being assaulted by the modern ways of construction. Besides people's out-date concept on the "earth house", the lack of high qualified technologies is also an obstacle for the preservation, restoration and new construction. Therefore, scientific and application research on earth architecture and construction technology is urgent.

### 1.1.3 Rammed earth practice of Professor Wang Shu

As the promoter of the academic concept of the Architecture School, Prof. Wang Shu had experimented on earth as early as the year 2000, making a sculpture with earth in a contemporary art exhibition. The rammed earth wall used as a sculpture was dismantled three months later for the reason that it was considered to be an unbeautiful work or too "outdated" by the organizer. Prof. Wang Shu thought the ending for this rammed earth wall—dust returns to dust and earth returns to earth—was not against the application intention of the rammed earth. The earth used for the wall



大理民居生土的多样性应用，云南  
Diversity application of earth in folk houses in Dali, Yunnan, 04/2012



在当时之所以得以实施，很大程度上是因为人们还能够认同茶室所需的趣味性。

在以上两次夯土施工中，都使用了钢模板。之所以选用钢模板，除了为保证墙体质量外，主要原因还在于希望能将夯土纳入现代的施工系统。在材料的使用上，两次都在生土内添加了石灰。在夯第一个雕塑作品时，由于水分过多、拆模不及时等缘故，墙体曾塌过一次；宁波的茶室，土中除了添加石灰，还添加了粉状的石头碎屑和水泥，均为了增加墙体强度，但最终夯土墙上还是出现了大量的细碎裂缝。

目前正在施工的“水岸山居”夯土墙体，为了避免以往的问题，在材料的配比和制备、模板系统和夯锤的选用上都遵循了法国 CRATerre 生土建筑研究中心的现代方法。从前期的试验墙体的结果来看，无论从墙体质量还是从外观效果上都基本达到设计要求。尽管如此，作为一个公建项目，在夯土墙表面是否适宜直接用于旅馆房间的内墙的问题上，人们还是心存顾虑。此外，考虑到抗震要求，夯土墙作为填充墙体镶嵌于钢筋混凝土框架中，但总高度高达 8m 左右，厚度仅为 60cm。这些夯土应用的多项尝试都有待于建成后时间的检验。

王澍教授表示，他对水岸山居的夯土建造有信心，同时也看好夯土在中国的发展前景，而且将身体力行地在今后的项目中更大规模地使用。作为当今最有影响力的本土建筑的实践者，他的建筑作品必将成为我国越来越多当代建筑的仿效对象，这对夯土乃至生土建造在中国的复兴必将起到积极的引导作用。

综上所述，在王澍教授引领下的建筑艺术学院，有必要建立针对生土建筑研究和应用的实验室，以提供教学、科研和工程的技术支持。此外，我院与法国格勒诺布尔国立高等建筑学院生土建筑研究中心，即联合国教科文组织“生土建筑、建造文化和可持续发展”教席所在的 CRATerre 实验中心的合作，为实验室的建立和发展提供了极其有利的条件。



左：夯土雕塑，王澍，杭州太子湾公园，浙江；右：夯土雕塑墙体建成三个月后被拆除

Left: Rammed earth sculpture, Wang Shu, Hangzhou Taiziwan Garden, Zhejiang.; Right: Rammed earth sculpture dismantled three months after being built, 02/2001 (from *The Beginning of Design*, p120/128)

was exactly the earth from the excavation of the foundations of the other artists' sculptures. But this implies that it was generally unacceptable of the local construction way with rammed earth. In 2006, Prof. Wang Shu again used rammed earth for the enclosure walls for his Tea House of the Five Scattered Houses project in Ningbo. The successful implementation of the rammed earth wall then, to a large degree, was due to people's recognition of the charm of a tea house.

In the construction of the two rammed earth projects, both used steel formwork. The reason for this was not only because of the guarantee of the quality of the walls but also in the hope of integrating the rammed earth into modern constructional system. In the application of the material, lime was added in both of the projects. In the sculpture project, the wall had been collapsed because of the over-use of water and lag of the dismantling of the formwork. In the Tea House in Ningbo, the earth was mixed with lime as well as stone powder and cement; the purpose was to enhance the strength of the walls. But as a result, there appeared a lot of tiny cracks on the walls.

In order to prevent the above problems for the rammed earth walls for the under construction project "Tiles Hills", the proportion and preparation of the materials, the choice of the formwork system and rammer all followed the modern methods of CRATerre. From the previous testing result, both the wall quality and the exterior appearance basically met the design requirement. Though, as a public project, whether it is feasible to use the rammed wall directly as the interior wall of the hotel rooms is still in question. Besides, in consideration of the anti-earthquake requirement, the rammed earth wall is being filled in the reinforced concrete frame, but the general height should be about 8 meters and only 60 centimeters thick. These several attempts on the application of the rammed earth have to wait for tests after construction.

Prof. Wang Shu said that he was very confident about the rammed earth construction of the project and also about the prospect of rammed earth in China. He would also practice himself on application of rammed earth in the future larger scale projects. As the most influential practitioner of local architecture, his architectural works will increasingly be the imitation models of contemporary architecture in China, which will be the positive element for the renovation of resurgence of rammed earth or even earth construction in China.

In conclusion, the Architecture School, under the guidance of Prof. Wang Shu, is necessary to establish a lab centering on earth architectural researches and applications in order to support teaching, research and engineering technologically. In addition, the collaboration between our school and the



水岸山居项目施工现场，王澍，中国美术学院校园，浙江  
Building site of project "Tiles Hills", Wang Shu, CAA campus, Zhejiang, 04/2012



## 1.2 实验室建设的目的

### 1.2.1 课程教学

本院建筑系的本科教学一直以来强调动手实验，要求一、二年级本科生主要通过动手实验进行学习，已开设的建造相关课程有木工基础、砌筑基础、金工基础。实验室成立之后，在三至五年级的课程设置有，也将设置至少两门结合了设计与建造的综合课程，由此将建造观念贯穿整个建筑学五年的教学，形成一套富有本土特色的建造课程体系。其中，夯土建造课程至今已开展了三次，将在下文中详细描述。

### 1.2.2 课题研究

本院建筑系立足于中国本土建筑，对本土建筑的材料及其建造富有紧迫的保护与发展意识。为此，建造实验室的重要作用之一就是为作为国家级课题的浙江省乡土建筑建造方面的研究提供强大的技术保障，如建立乡土建筑建造实体资料库，并进行传统材料改良性实验及新材料应用实验，在保护传统的同时不拘泥于传统方式，致力于为传统建造引入现代的建构意识。在本省研究的基础上，进而发展到对全中国乡土建筑建造的整理和研究，梳理出一整套中国本土建筑的建造体系。同时，此实验室成果将应用于教学，甚至让学生共同参与共建建造资料库，最大限度地让实验室服务于教学和研究。目前，乡土建筑普查已覆盖了浙江省大小几十个村落，并仍在持续进行中，计划于明年完成共 133 个核心村的普查，正式出版研究成果。

此外，基于实验室的建设，我院还将开展一系列与建造有关的国际学术交流活动。如去年 12 月份刚刚举办的“夯土建筑保护与再发展”会议，交流的同时也将浙江及全国的本土建造带入国际视野。

### 1.2.3 工程实践

与乡土建造研究平行的还有现代建筑新材料的建造研究，利用实验室的加工成型设备和技术测试设备，在材料的建造形式上大胆创新，融入设计艺术理念，对各种材料的应用可能性进



建筑艺术系一年级的建造基础课程：木工基础课和砌筑基础课

Construction course for Grade 1 of Architecture Department: Basic Carpentry course (photography: Chen Jiahui) and Basic Masonry course

National Superior School of Architecture of Grenoble with CRAterre-ENSAG Research Laboratory as UNESCO chair of *earth architecture, building cultures and sustainable development* has provided favorable conditions for the establishment and development of SCL.

## 1.2 Objectives of SCL

### 1.2.1 Curriculum teaching

The undergraduate teaching of the Architecture Department has been emphasizing experiment with hands. The first and second year students mainly learn with hand experiments with courses relative to construction including basic carpentry, basic masonry and basic metalworking. After the establishment of the lab, at least two more integrating courses will be added into the curriculum of the third, fourth and fifth year students combined design and construction together. Therefore, the construction concept runs through the whole teaching system of the five-year undergraduate architectural education. A construction teaching system with local features has been formulated. The rammed earth courses have been implemented for three times, which will be elaborated in the later part of this thesis.

### 1.2.2 Research project

The Architecture Department of the school focuses on Chinese local architecture and feels the urgency of protection and development of the local materials and constructions. Therefore, one of the important functions of the lab is to provide technology guarantee for the national research project centering on the local architectural construction of Zhejiang province, such as setting up a substantial local architectural construction database and doing experiments on the improvement of traditional materials and application of new materials; it is not restricted by traditional methods though it is to protect the tradition; it devotes to introduce modern constructional concept to traditional construction. Based on the research of Zhejiang province, it will expand its research scope to the whole country to search out a complete local architectural construction system of China. At the same time, the experiments results will be applied into teaching, or even involve the students into the participation of the database set-up. The lab will serve teaching and research as much as possible. So far, the local architectural survey has covered dozens of villages of the Zhejiang province and continues to proceed. According to the plan, 133 villages will be surveyed by next year and will publish the survey results.



建筑艺术系四年级的建造课程

Light steel structure construction course for Grade 4 of Architecture Department, 03/2012

行建造性实验,真正实现建造领域中艺术与技术的有效结合。

至今年 4 月，实验室已完成王澍教授设计的中国美术学院象山中心校区内“水岸山居”工程的夯土建造的材料测试、配比和建造试验工作，这部分内容将于来自 CRATerre 的 Marc Auzet 和 Juliette Goudy 的论文中详细描述。目前，实验室仍在跟进此工程的夯土现场施工，提供及时的技术指导。

### 1.3 实验室建设的途径

与 CRATerre 的合作是实验室建设的重要途径。这一合作首先明确了实验室在建设初期的研究方向，即生土。

建筑艺术学院计划派两名教师赴法参加 CRATerre 的 DSA-Terre 课程学习。本人作为第一个参加学习的教师，在法国的六个多月时间学习了生土材料及其建造应用的知识和技能，了解了实验室的配备和运作，为回国后实验室的建设提供了知识和技术储备。同时，本人也在院领导的支持下积极促进我院和 CRATerre 进一步的交流与合作。两位法国交流学者 Marc Auzet 和 Juliette Goudy 在美院的工作，为实验室的建设及一系列夯土建筑项目的研究提供了更加有力的技术支持。

第一届“乡土建筑资源与创新发展”大型国际学术系列论坛  
 1st international symposium "Localized Architecture Resources and Innovational Development"

# 夯土建筑保护与再发展

## The Protection and Redevelopment of Rammed Earth Architecture

# 12.20-12.21.2011

### 中国美术学院建筑艺术学院 School of Architecture, China Academy of Art

**主题报告题目 Titles of Keynote Speeches**

时间: 2011年12月20日      地点: 中国美术学院建筑艺术学院14号楼报告厅  
 Date: 20th December 2011      Venue: Auditoria Room, Building 14, School of Architecture, CAA

## Anne-Monique Bardagot 夯土的再发展与建筑教育 The Redevelopment of Rammed Earth & Architectural Education

谢英俊 Hsieh Ying Chun 金木水火土——土建筑新解  
 Gold, Wood, Water, Fire, Earth—New Interpretation of Earth Building

穆钧 Mu Jun 西部贫困农村地区生土建筑设计研究与实践  
 Practical Study of Earth Architecture in Poor Rural Western China



### 会议日程

**第一天: 12月20日 (周二)**  
 8:30 签到, 8:30-9:00 开幕式  
 9:00-10:00 主题报告  
 主持人: Anne-Monique Bardagot  
 演讲者: 谢英俊 中国美术学院建筑艺术学院  
 地点: 建筑艺术学院14号楼报告厅  
 10:30-11:30 茶歇  
 11:30-12:00 主题报告  
 主持人: 穆钧  
 演讲者: 穆钧 中国美术学院建筑艺术学院  
 地点: 建筑艺术学院14号楼报告厅  
 12:00-13:00 午餐  
 13:00-14:00 茶歇  
 14:00-15:00 主题报告  
 主持人: 穆钧  
 演讲者: 穆钧 中国美术学院建筑艺术学院  
 地点: 建筑艺术学院14号楼报告厅  
 15:00-17:00 茶歇  
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Left: Poster of 1st international symposium "the Protection and Redevelopment of Rammed Earth Architecture"; Right: Experimental wall for "Tiles Hills", Construction Workshop of Architecture School



Additionally, our school will develop a series of international academic exchanges relative to construction based on the lab establishment. For example, last December the school hosted an international conference with the theme of *The Protection and Redevelopment of Rammed Earth 2011*, besides the objective of exchanges nationally and internationally on the conference, it also brought the local construction of Zhejiang province or even of China into an international scope.

### **1.2.3 Project practice**

Paralleled to the local construction research, there is a construction research on modern new architectural materials, which will utilize the processing facilities and technical testing facilities to make bold innovation on architectural form of materials, integrate design and art theories, do constructional experiments on the application possibilities of various materials and make effective combination of arts and technologies in the field of construction.

Till April of this year, the lab has finished the material analysis, reformulation and construction experiments for the “Tiles Hill” on the Xiangshan campus of CAA designed by Prof. Wang Shu. In the thesis of Marc Auzet and Juliette Goudy from CRATerre will describe in details on this. So far, the lab is still assisting the rammed earth construction of the project and providing technical instructions when it is necessary.

## **1.3 Approach of the establishment of SCL**

The collaboration with CRATerre is an important approach. The collaboration makes clear of the research direction of the lab from the beginning, that is earth.

The Architecture School of CAA planned to have two teachers to participate the DSA-Terre program in CRATerre. As the first teacher from the school to participate the program, I spent six months in France, learning knowledge and skills of earth material and construction application, getting to know the facilities and operation of the laboratory, which provided necessary knowledge and technology for the establishment of SCL. At the same time, I also promoted the exchange and collaboration between our school and CRATerre with the support of the dean. The two exchange scholars from France, Marc Auzet and Juliette Goudy, have provided great technical support for the establishment of SCL and researches of rammed earth projects.

## 2 实验室建设

可持续建造实验室的筹建、建立和运转得到了中国美术学院多方面的支持,包括场地、资金、政策和人员等。实验室资金来源于浙江省属高校实验室建设专项项目及中国美院标志性成果建设专项项目,共计 290 万人民币,除了生土建筑实验室,还包括了木工、金工等其他建造实验室。资金用于实验室改、扩建,试验材料的购买,设备工具的购买或制作,和相应的维修维护损耗等,以及实验室人员的引进与培养。为此,学院建立经费保障制度,对立项建设、建设中期检查到结题验收、经费核拨等过程进行了规范。

本实验室的筹建始于 2009 年 7 月,定位于开展材料研究及其建造实验,包括了生土在内的一系列乡土建筑材料,如砖、石、木和竹等,并逐步确定生土为实验室首个重点研究对象。

2009 年 7 月 -2010 年 12 月,第一批设备的采购清单逐步确定并完成招标,2011 年 8 月实验室场地改造完成,9 月设备陆续到位,实验室的建设进入实质性阶段。

在此阶段,实验室的建设与实验室工作的开展几乎是同时进行的,正是在开展夯土课程的教学和夯土工程的试验过程中,不断完备实验室设备工具的配置,优化实验室的场地布局,同时培养了实验室的工作人员。如今,实验室的配备已能进行完整的生土材料分析测试,完全具备开展大型夯土建造试验的能力,并逐步完善了土坯、压制土砖等其他生土建造技术的配置。期间,来自 CRATerre 的 Marc Auzet 和 Juliette Goudy 作为实验室建设的专业引进人员,尽职尽责,使得实验室的建设持续顺利进行。



可持续建造实验室,中国美术学院象山中心校区 13# 楼  
Sustainable Construction Laboratory, 13# Xiangshan Campus of CAA, 03/2012

## 2 Establishment of SCL

The preparation, establishment and operation of SCL have gained great support from China Academy of Art in aspects such as the space, fund, policy and staff. The fund of the lab is from the special funds for laboratories of higher institute and the special fund for research projects of CAA, altogether 2900,000 RMB. This fund is for earth architecture lab, as well as for the carpentry, metalworking and other construction labs. The fund is used for the space renovation, expanding, purchase of the test materials, purchase and production of the equipment and tools, relative repair and maintain cost and employment and training of the personnel. The school established guarantee policy for the fund, setting up rules from the process of establishing, mid-term examination to the final result examination and fund assignment.

From the preparation of the lab in July 2009, its set position was to do researches on materials and construction test, including local architectural materials such as earth, brick, stone, wood and bamboo, and took earth as its first focused research object.

From July 2009 to December 2010, the first list of the equipment was fixed and finished its bid; in August 2011, the renovation of the lab space was finished; in September the equipment arrived and the establishment truly started.

At this phase, the establishment of the lab and work in the lab almost happened at the same time, it was just during this period the equipment and tools of the lab were being increasingly improved and the layout of the space was perfected through the rammed earth courses and tests for the rammed earth project. At the same time, the staff of the lab was trained. By now, the equipment of the lab



可持续建造实验室内部，中国美术学院象山中心校区 13#  
Interior of Sustainable Construction Laboratory, 13# Xiangshan Campus of CAA, 03/2012



2.1 实验室的选址与改建

我院可持续建造实验室的生土建筑实验室设在建筑艺术学院 13# 的底层，总面积约 260m<sup>2</sup>。利用原有空间的特点，分别设置生土材料分析实验室和建造工作坊，各约 130m<sup>2</sup>，分区明确，且联系紧密。

实验室的地点于 2010 年 11 月确定之后，王澍教授指导了对实验室的改建，2011 年 7 月开始施工，为时 2 个月。

实验室原为两间大教室，主要的改建在于在建造工作坊打开一堵柱网间的墙体，安装了一扇面宽 5.6m 的大型移门，方便材料和设备等的进出。此外，在建造工作坊的顶部安装了电动小车，以便于大型重物的提放。在家具的设计和制作上，采用了橱柜和台面的通用设计，可以根据实际的使用情况自由组合设置。其他如水电等基础设施也做了相应的调整。

2.2 生土材料分析实验室

由于第一批设备采购主要针对的是材料分析测试，因此，生土材料分析实验室从一开始即能够比较顺利地投入使用。

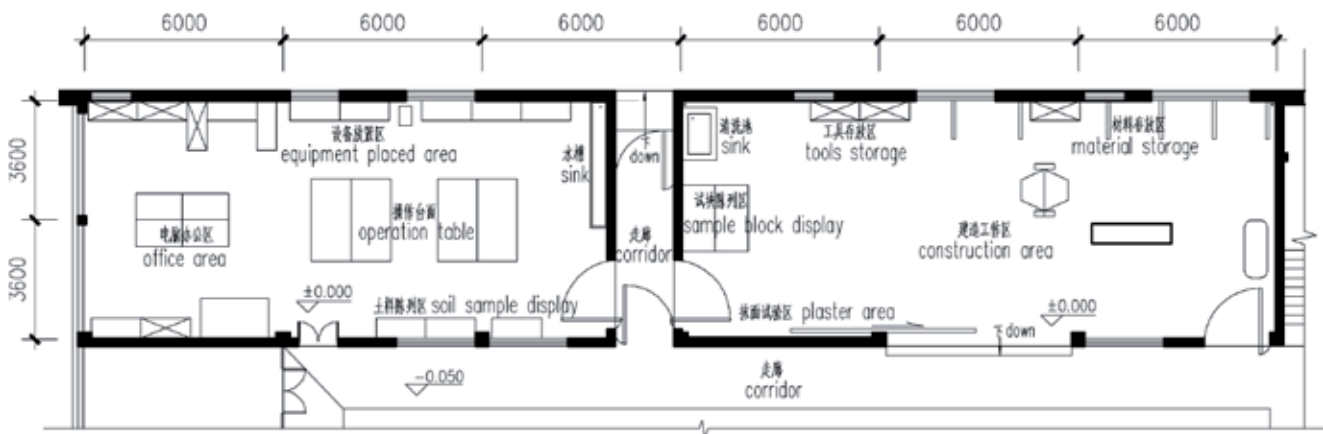
2.2.1 实验室的布局

2011 年 9 月，新学期的开始，材料分析实验室正式启用。此时，考虑到工具设备存放和使用的合理性与方便性，对实验室的空间布局和家具利用进行了调整。

2.2.2 设备工具的配置

我院的生土材料分析实验室的设备配置主要参考了 CRATerre 实验研究中心的材料分析实验室，详细的配置可参见《土壤鉴定试验手册》。目前为止，实验室已能全面开展生土材料的所有测试，包括：

- 1) 野外测试
- 2) 实验室测试
  - 粒径分布分析——筛分
  - 粒径分布分析——沉淀
  - 粘土膨胀性测试



可持续建造实验室平面布置图，中国美术学院象山中心校区 13# 楼底层  
Layout plan of Sustainable Construction Laboratory, ground floor of 13# Xiangshan Campus of CAA

is able to do complete earth material analysis tests, with the full ability to carry out rammed earth construction tests of large scale. Besides, the facilities for earth construction technology such as adobe and compressed earth block were also improved basically. As visiting staff for the establishment of the lab, Marc Auzet and Juliette Goudy from CRATerre devoted themselves to the lab to ensure the success of its establishment.

## 2.1 Space reconstruction

The space for earth architectural lab of SCL is in the ground floor of Building 13, Architecture School, CAA, with an area of about 260 m<sup>2</sup>. Considering the characteristics of the original space, it was divided into material analysis lab and construction workshop, with an area of 130 m<sup>2</sup> each. There is a clearly boundary but very closely related.

When the space for the lab was decided in November 2010, under Prof. Wang Shu's instruction, the reconstruction of the space started from July 2011 and lasted for two months. The original space was two big classrooms. The main reconstruction point is to make an opening on the wall between two columns at the construction workshop side. A big sliding door of 5.6 meters wide was fixed as the access of materials and facilities. Besides, an electrical cart was fixed at the top of the construction workshop for lifting and loading of large and heavy things. For the design and production of the furniture, the cabinets and tabletops could be combined freely according to specific purposes. Other adjustment including infrastructure of water and electricity was also made accordingly.



材料分析实验室内部，中国美术学院象山中心校区 13#  
Interior of Material Analysis Laboratory, 13# Xiangshan Campus of CAA, 03/2012

## 2 实验室建设

界限含水率——塑性指数，液限 & 塑限

标准 Proctor 击实测试

渗透性测试

粘结性测试

此外，实验室还配备了热工性能测试设备和抗压强度测试设备，因此也可以对生土构件如夯土试块等进行传热系数和抗压强度的测试。

### 2.3 建造工作坊

与材料分析实验室的情况有所不同，建造工作坊的设备和工具等并未事先采购。因此，建造工作坊可以说是完全在使用中根据实际需要逐步配置完善的。这一建设过程历经两次建造工作营，即第一次的夯土建造课程和第二次的夯土试验墙建造工作营。

#### 2.3.1 工作场地的布置

基于对当地用土的土质鉴定，明确了所用土由于粘土含量过高，作为夯土材料时不能独立使用，必须与砂和砾石进行配比。此外，由于所用土是从校园内“水岸山居”工程基地上直接取用，土壤含水率高，易结块，因此与其他材料混合前必须进行干燥和破碎，才能满足使用要求。

为了以最有效的方式进行备土，根据特定的夯土建造流线调整了建造工作坊的场地布置。整个建造流线围绕着待建墙体，形成连续的操作流线，尽量避免工作场地的浪费，提高工作效率：

干燥——破碎——储存——搅拌——醒土——夯筑

#### 2.3.2 工具设备的配置

经过 2011 年两次夯土建造工作营，建造工作坊为机械夯土建造的配置已完全到位。由于在



材料分析实验室的部分设备，中国美术学院象山中心校区 13# 楼  
Equipment and tools of Material Analysis Laboratory, 13# Xiangshan Campus of CAA

## 2.2 Material Analysis Laboratory

Since the first batch of facilities were mainly for material analysis and testing, the earth material analysis lab came into use from the very beginning without much difficulty.

### 2.2.1 Layout of the laboratory

The material analysis lab officially put into use at the beginning of the new semester, September 2011. At that time, the space layout and furniture utilization were adjusted for better and more convenient storage of the tools and equipment. (Image on p24)

### 2.2.2 Equipment and tools of the laboratory

The equipment of the earth material analysis lab was mainly based on the one in CRATerre. The detailed list was included in the *Soil Identification Manual*. So far, the lab is able to carry out all tests for earth materials, including:

- 1) field test
- 2) laboratory test
  - Grain-size distribution analysis – Sieving test
  - Grain-size distribution analysis – Sedimentation test
  - Clay dilatability test
  - Atterberg's limits: plasticity index, liquid limit and plastic limit
  - Standard Proctor test
  - Permeability test
  - Cohesion test

Besides, the lab is also equipped with thermal performance test equipment and compressive strength test equipment, so it could also do tests of conductive coefficient and compressive strength tests on earth components such as rammed earth testing blocks.

## 2.3 Construction Workshop

It was different with the material analysis lab, the equipment and tools of the construction workshop had not been bought before the establishment of SCL. So it could be said that the construction



研究生在使用材料分析实验室，中国美术学院象山中心校区 13#  
Material Analysis Laboratory in use of the graduate students, 13# Xiangshan Campus of CAA, 03/2012



2010 年还开展过一次夯土建造课程，当时制作了三套传统的夯土模板和夯锤等工具，部分损坏，但仍保留下一部分。因此，工作坊能开展手动和机械的夯土建造试验。

除了自制夯土模板，建造工作坊中的所有工具和设备都尽量在杭州本地购买。一来降低采购和未来的维修成本，二来借此检验当地设备的质量，为日后大规模的工程施工做准备。机械夯土建造中最重要的几项设备和工具包括：搅拌机、气动夯锤、空压机、空气调节器、模板和脚手架。

### 1) 搅拌机

所购为标准的水平轴搅拌机，其生产力足以应对实验室内的建造规模。由于未能买到破碎机，因此此搅拌机兼作破碎机。作为破碎机时，在搅拌桶内放入大石块配合使用。

### 2) 气动夯锤

购买的国产气动夯锤较轻，便于操作。相对于进口产品，这种气动夯锤性价比较高，但需要定期的检查和调整，确保良好的运转。推荐每个夯土工人应配备至少 1.5 个夯锤。

### 3) 空压机和空气调节器

此空压机排气量为  $2\text{m}^3/\text{min}$ ，提供的动力可供两个气动夯锤同时工作。不足在于体积庞大且笨重，不便移动。

为了使空压机提供的气流保持稳定的压力，需配合使用空气调节器。使用的气源处理器二联件，不仅稳定压力，还为夯锤起到润滑作用，使得对夯锤的操作变得顺畅，有助于材料在均匀的压力下紧密压实成匀质墙体。

### 4) 模板系统

第二次工作营时，Marc 设计了模板系统，并由 CAA 建筑艺术学院的木工工作坊制作完成。模板设计的基本原则是制作成本低、重量轻和便于拆支模的操作，适应当前和将来的试验需要。



建造工作坊内部，中国美术学院象山中心校区 13# 楼  
Interior of Construction Workshop, 13# Xiangshan Campus of CAA

workshop was equipped gradually according to the needs in the process of using it. During the establishment, there were two construction workshops, the first rammed earth construction course and the second rammed earth testing wall construction workshop.

### 2.3.1 Layout of working space

Based on the local earth quality identification, it has been proved that the proportion of clay is too high. The earth could not be used alone as the rammed material. It has to be mixed with sand and gravel. What's more, the water proportion of the earth used, which had been excavated directly from the project site of the "Tiles Hill", was too high and easy to clot, so it had to be dried and smashed before mixing with the other materials; otherwise it couldn't meet the usage requirement.

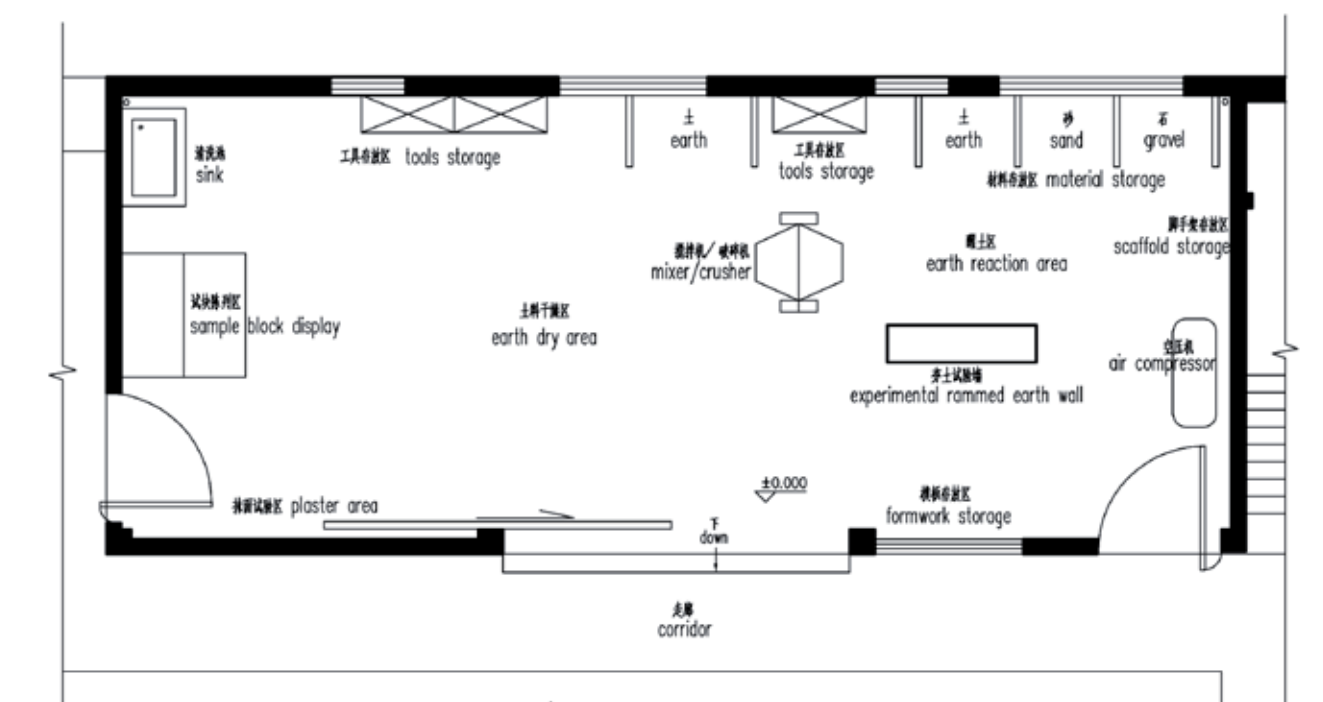
In order to prepare the earth in the most effective way, the site layout of the construction workshop was adjusted according to the special rammed earth production line. The whole production line surrounded around the to-be-built walls to form a continuous operating line and prevent as much as possible the waste of site and improve working efficiency:

Drying — smashing — storing — mixing — reaction — ramming

### 2.3.2 Equipment and tools of the workshop

After the two rammed earth construction workshops in 2011, the construction workshop was fully equipped with facilities for the mechanical rammed earth construction. Since there had been another rammed earth construction in 2010, the prepared three sets of traditional rammed earth formwork, rammers etc. were left with partially damage. Therefore, the workshop is equipped both for hand ramming earth construction experiments and mechanical ones.

Apart from the self-made rammed earth formwork, we tried to buy all the equipment and tools for the construction workshop in Hangzhou. On the one hand, it would reduce the cost of purchase and future repairing; on the other hand, it was possible to examine the quality of local equipment and



建造工作坊平面布置图，中国美术学院象山中心校区 13#  
Layout plan of Construction Workshop, 13# Xiangshan Campus of CAA

事实上，最初设计的模板虽然轻质方便操作，但不够坚固。在机械夯锤巨大的冲击力下，木板上产生了许多裂缝，部件连接处的接头逐渐松动。因此，又将模板进行了相应的改进，通过增加板和连接件的厚度，加强不同部件间的连接来提高整个模板的强度。改进后的模板虽然更重，但仍可以由两个人完成支模操作，只是需要更多的时间。事实证明，改进模板足够坚固，承受得了机械夯锤的压力。

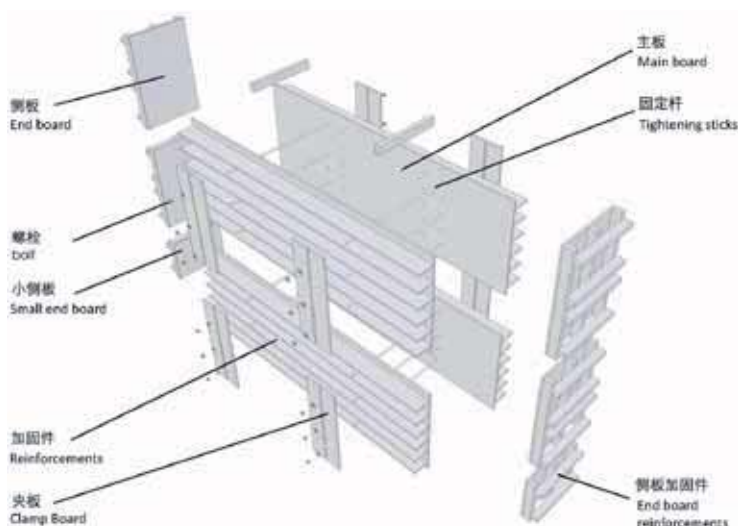
在此模板系统中，使用了 1.2m 长的普通螺杆和螺栓作为固定杆件来安装固定模板。出现的问题是，螺杆在拆模时难以拔出，且在拔出过程中会破坏墙体的表面。同时，土会粘着在螺杆表面，使其难以再次使用。推荐使用混凝土工业中特制的加固杆件，但暂时未能在杭州买到这样的杆件。

此外，在 2012 年 3 月的第三次工作营，即生土建筑培训的过程中，为了配合培训中其他生土建造技术的教学，实验室陆续自制了一些制作土坯、压制土砖的木制模具和小型夯锤，添置了抹面用的各式抹灰刀等，生土建造配置日益完善。

## 2.4 实验室人员培训

除了实验室硬件设施设备的配置，我院同样重视实验室人员的培养。

在可持续建造实验室的筹建初期，我院即派出人员到 CRATerre 学习和考察。2010 年 5 月，作为实验室筹备人员，我赴法参加了第 9 届国际生土节，首次接触到现代的、专业的生土材料研究和建造。回国后，参考 CRATerre 的材料分析实验室的设备清单，结合我国相应的土工试验方法，具体确定了实验室首批设备的引进。2010 年 12 月至 2011 年 6 月，我在 CRATerre 参加了 DSA-Terre 的课程学习，在此期间还特别对实验室的各项装备配置及使用、相关课程的设置及开展进行了考察。回国后，这些所学技能和考察信息，无论在实验室的筹备阶段，或是建



建造工作坊的现代模板（由 Marc Auzet 设计）  
Modern formwork of Construction Workshop (designed by Marc Auzet)

prepare for the larger scale of projects in the future. The most important equipment and tools in the mechanical rammed earth construction include: mixer, pneumatic rammer, air compressor, air adjuster, formwork and scaffolding.

#### 1) mixer

The purchased mixer is the standard horizontal axis one. Its productivity is enough for the scale of construction inside the lab. Since there was no access to buy the smashing machine, the mixer also plays the role of smashing machine. When it is used as smashing machine, big stones will put into the mixing barrel to assist.

#### 2) pneumatic rammer

The bought domestic pneumatic rammer is comparatively light, and easy to operate. Compared with the imported one, this rammer is more cost effective, but it still needs to be checked and adjusted regularly in order to ensure the well performance. It is recommended that every worker should be equipped with at least 1.5 rammers.

#### 3) air compressor, air adjuster

The output volume of the air compressor is 2 m<sup>3</sup>/min, the power provided enables two pneumatic rammers working at the same time. The disadvantage is that its volume is too big and heavy so it is not convenient to be moved.

In order to enable the air compressor to provide air current with stable pressure, air adjuster is needed to assist. The functions of the applied two pieces of air source processor not only keep the pressure stable but also lubricate the rammer. In this case, the rammer is more operable, so that the material will be rammed into well distributed walls under even pressure.

#### 4) formwork system

In the second workshop, Marc designed a formwork system, which was then produced by the



生土建筑培训，建造工作坊

Training of earth architecture, Construction Workshop, 03/2012



成后的工作运转阶段都是至关重要的。

2011 年 9 月至 2012 年 4 月，借助于来我院实习交流的 Marc 和 Juliette 的专业知识和技能，本实验室开展了一系列生土材料测试和生土建造技术的理论和实践的培训。参加培训的人员包括实验室的专职工作人员、建筑艺术系的教师和研究生。此外，通过夯土建造课程，部分本科生学习了生土的基础知识和夯土建造技术；通过金工实验室的夯土墙建造，部分参与“水岸山居”工程施工的工人学习了现代夯土技术。

其中，2012 年 3 月开展的为期 4 周的生土培训是最为专业和完整的一次培训，其中一个重要的原因在于所需的试验和建造的工具设备等刚刚全部到位，能够完整地展开所有测试。Marc Auzet 和 Juliette Goudy 作为主讲教师，亲自讲解、示范并指导了各项生土试验和建造实践。

### 2.4.1 培训对象和目的

培训对象：实验室专职人员 1 人、建筑艺术系教师 2 人，和王澍教授的硕士研究生 8 人，共 11 人。

培训目的：为了保证实验室日后的正常使用和运转，实验室专职人员必须理解实验原理、掌握实验设备的使用方法，能够独立完成所有的测试试验，和进行建造的实践操作，从而辅助教学、配合研究工作。相关师生也应了解实验原理及操作，以便更好地开展生土教学和研究工作。

### 2.4.2 培训时间和内容

此次培训主要包含三方面内容：初识生土材料、土壤鉴定试验和生土建造技术，均包含了理论授课和实践操作环节。

培训内容首先是通过动手实践来亲身体验生土与建造有关的性能，由此理解生土的使用方式与其性能紧密相关；在此基础上，通过科学的分析试验对生土进行鉴定，进而判定所测试的



生土建筑培训，建造工作坊

Training of earth architecture, Construction Workshop, 03/2012 (photograph: Juliette Goudy, Marc Auzet)

carpentry workshop of Architecture School. The basic principle for the design of the formwork is low production cost, light and easy to install and uninstall, so that it could meet the current and future experiments requirement.

In fact, the initial designed formwork was light and easy to operate but not strong enough. Under the intense force of mechanical rammer, there appeared a lot of rips on the wooden planks and the component links became loose. Therefore, the formwork was improved accordingly, the thickness of the planks and components increased, the links between components were enhanced to raise the strength of the whole formwork. The improved formwork is heavier but still could be operated by two people, only need more time. It has been proved that the improved formwork is strong enough to endure the pressure of mechanical rammer.

In this formwork system, the common screw rod of 1.2 meters long and nut were used to fasten the formwork. The emerging problem was, the screw rod was difficult to be pulled out in the uninstallation and would destroy the surface of the wall in the pulling process. At the same time, the earth would stick on the surface of the screw, making the screw impossible to be used again. It was recommended to use the fasten component especially for the concrete industry, but it could not be found in the Hangzhou market for the time being.

Then in the third workshop in March 2012, namely the earth architecture training, the lab provided some self-made wooden molds and small rammers for the adobe, compressed earth block, and various kinds of trowels for the plaster were added. The equipment of earth construction is increasingly improved.

## 2.4 Personnel Training

Our school attached much importance to the personnel training of the lab besides the equipment of the lab hardware.

In the initial stage of the preparation of the establishment of SCL, our school sent staff to study and investigate in CRATerre. In May 2010, as member of the preparation team, I went to France to participate the 9<sup>th</sup> International Earth Festival and for the first time I got to know the modern, professional researches and constructions with earth material. After I returned to China, the first list of the equipment for the lab was decided with reference to the facilities of the material analysis lab of CRATerre and the earth testing methods of our country. From December 2010 to June 2011 when



生土建筑培训，野外测试和理论授课

Training of earth architecture, field tests (photography: Juliette Goudy) and theory lessons

生土适用的建造技术，并能进行材料的配比改良；最后，动手进行生土建造，如夯土和抹面，掌握相应的建造技术，进一步加深对材料的理解。

值得一提的是，在此次培训之前，Juliette 和 Marc 已基本完成了《土壤鉴定试验手册》英文版的编写，并由我翻译成了中文。该手册在生土试验的培训中，极大地方便了教学。

人员的培训对实验室今后保持有效的运转极其重要，只有通过实验室人员的正确有效地使用，实验室才能在生土的建造教学、工程应用和课题研究中持续发挥重要的作用。为了使培训更为全面和详细，原计划 3 周的课程延长成了 4 周。从培训的效果来看，基本达到了培训目的。

2.5 实验室建设的经验总结

从 2009 年 7 月实验室准备筹建，至 2012 年 3 月实验室的建设基本到位，花费近三年时间。在这期间，经历了实验室研究方向的逐步明确，工具设备配置的计划制定、审查、招标和采购，实验室人员的引进和培训，以及在课程教学和夯土建造试验过程中的磨合与完善。

这是一个漫长的过程，但从时间节点上看，主要的原因在于实验室计划申报、审批，和工具设备的招标、采购和到货等一系列环节是需要程序上的时间安排。排除这些不可控因素，这仍是一个漫长且不乏曲折的过程，因为我院的生土建筑实验室是国内第一个将生土作为建筑材料进行研究的实验室，必然需要一定的摸索过程。

在此摸索的过程中，可以看到以下几点是实验室得以顺利建成并良性运转的重要因素：

1) 国际交流与合作

王澍教授的学术追求和国际视野，促成了我院与 CRA Terre 的合作。这一合作提供的专业知识和技术，使实验室的硬件配备从一开始就达到了该领域的先进水平，并有效利用。此外，通过此合作引进或培养的实验研究人员在实验室的建设中起到了至关重要的作用，并将在今后实验室的日常运作中持续发挥作用。

2) 资金和人员的支持

实验室的建设少不了资金的投入和人员的配置。在资金方面，实验室专项资金是比较充裕

生土建筑培训计划表  
(制定者：Marc Auzet、Juliette Goudy)





I was participating the program of DSA-Terre in CRATerre, I also made investigation of the deploy and usage of every facility, the setup and carrying out of the courses. After I returned to China, the information and skills I had acknowledged in France was critical both to the preparation of the lab and the operations after its establishment.

From September 2011 to April 2012, with the help of Marc and Juliette who came to our school for their internship and exchange, a series of earth material tests and trainings on the theory and practice of earth construction technology were made in the lab. The participants included the full-time staff of the lab, teachers and postgraduates of the school. Besides, from the rammed earth construction courses, some undergraduates have get to know the basic knowledge about earth and rammed earth construction technology; from the construction of rammed earth wall for the metalworking lab, some workers who are participating the construction of the “Tiles Hill” projects have got to know the modern rammed earth technology.

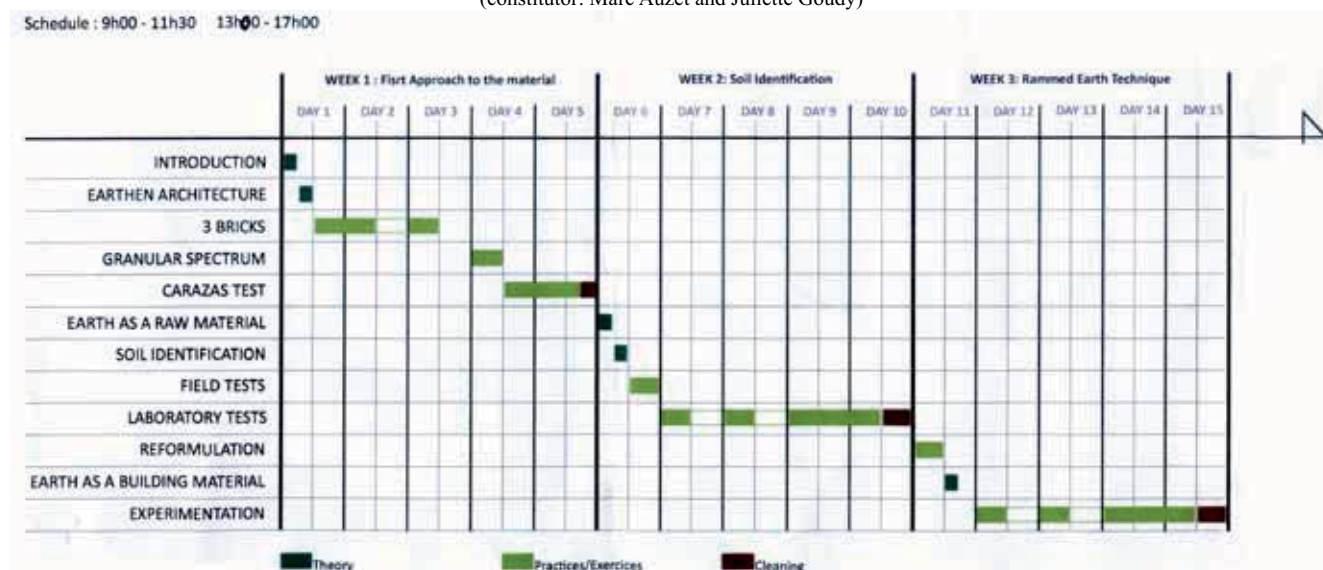
The training starting from March 2012 for four weeks was the most professional and complete training. One important reason for this was that the tools and equipment for testing and construction had all been fixed that could support all the tests in the lab. As the training teachers, Marc Auzet and Juliette Goudy explained, demonstrated, and instructed every earth test and construction practice.

#### 2.4.1 Trainees and training objectives

The trainees are: a full-time staff from the lab, two teachers from the Architecture Department, eight postgraduates of Prof. Wang Shu’s, altogether eleven persons.

The objectives include: in order to ensure the management and operation of the lab in the future, the full-time staff has to know the testing principles, the methods of using the facilities, be able to finish all the tests independently, do practices of constructions so that he has the ability to assist teachings and research works. The relative teachers and students should also know the testing principles as well as the operation in order to performance better in earth teachings and researches.

PLANNING OF TRAINING OF EARTH ARCHITECTURE  
(constitutor: Marc Auzet and Juliette Goudy)



的，因此除了通过招标程序中购买的实验测试设备外，后期又根据实际的使用情况，陆续添置了大量的建造设备工具。这些新添置的工具设备在当地购买，经济实用。

资金的充足也让人员的引进和培训成为可能。有了专业人员的参与，实验室的建设就能够有序、高效地进行，也才能保证实验室建成后能够持续正常地运作，服务于教学、科研和工程实践。

### 3) 实际应用的支撑

实验室的建设和运转，一方面配合开展生土建造教学，一方面作为浙江省乡土建筑资源普查课题研究的平台，另一方面为王澍教授的夯土工程提供技术服务。正是因为有可为，实验室的建设能够顺乎情势，并至今良性发展。

实际上，在筹建初期，在与 CRA Terre 充分开展合作之前，由于缺乏此领域专业人员，也没有先例可供参考，实验室的筹备走过一些弯路。比如，由于本人当时还未接受 DSA 课程的学习，在实验设备的购买配置时主要参照了 CRA Terre 提供的设备清单，致使设备多为进口，价格比同类国产的高出许多。在今后的设备再添置时，在保证质量的前提下，将首先考虑国产设备，节约成本。

作为中国首个生土建筑实验室的建成使用，能够为今后国内其他此类实验室提供借鉴。事实上，目前西安建筑科技大学建筑系在系主任穆钧教授的主持下也正在筹建同类实验室，其建设模式、设备配置等在很大程度上参考了我院的实验室，少走了弯路。

此外，关于实验室的核心技术工作，即生土鉴定测试，我将在 CRA Terre 提供的《生土鉴定试验手册》的基础上，结合我国土工试验标准，进行适当地调整，以期更好地用于我国的生土鉴定工作。



左：“水岸山居”夯土试验墙；右：实验室人员正在对工人进行现场培训，“水岸山居”夯土现场

Left: Experimental rammed earth wall for the "Tiles Hills" project; Right: members of SCL were training the workers on the "Tiles Hills" site. 04/2012

## 2.4.2 Training process

The training this time consists of three aspects: preliminary understanding of earth materials, soil identification tests and earth construction technologies; every aspect has theory lectures and practice operation. The specific schedule is as following:

It could be seen from this form, firstly the trainees personally experience the property of earth that is relative to construction through practice. On his basis, scientific analysis was made to test the earth, and then judge the tested earth was applicable to which construction technology and also improve the proportion of the mixed materials. Lastly, practice with earth construction, such as ramming the earth and plaster the surface. By such practice, the trainees would master the relative construction skills and know the materials better.

It is worth mentioning that before this training that Julieete and Marc had basically finished the English version of *Soil Identification Manual* that I had translated it into Chinese. The handbook played an important role in the training.

Such training is critical to the effective operation of the lab in the future. The lab is only able to run efficiently and continuously for the earth construction teaching, engineering application and researches when the staff of the lab knows how to use it correctly. In order to make the training more comprehensive and specific, the planned three weeks finally came to be four weeks. The outcome is comparatively satisfactory and meets the planned objectives.

## 2.5 Experience summary

From the preparation of the lab in July 2009 till the establishment almost finished in March 2012, it costs nearly three years. During this process, the lab has experienced gradually clearer research direction, the decision, examination, bid and purchase for the equipment, staff employment and training as well as the improvement during the process of teaching and rammed earth construction experiments.

This is a long process. But the main reason for this is because it depended on the procedure of the application for the lab plan, approval and bid, purchase and arrival for the equipment. Though without these uncontrolled elements, this was still a long process with many obstacles. Because the earth architecture lab of our school is the first one in China that takes earth as an architectural material to study, there must be a process of exploration.

During this process of exploration, there are some critical elements that attribute to the success of the establishment and benign operation:

### 1) international exchange and cooperation

Prof. Wang Shu's academic pursuit and intentional view of point made it successful the collaboration between our school and CRATerre. This collaboration provided professional knowledge and technology, and the hardware equipment of the lab was the most advanced from the very beginning and is used effectively. Besides, the lab researchers brought or trained by this collaboration has played a critical function to the establishment of the lab and will keeps functioning in the operation of the lab in the future.

### 2) budget and personnel support

## 2 实验室建设



左：《土壤鉴定手册》；右：《生土建筑·夯土技术教学手册》

Left: *Soil Identification Manual*; Right: *Raw earth architecture, rammed earth technique A pedagogic manual*



The establishment of the lab requires large fund and personnel. In the aspect of fund, the special fund for the lab is relatively abundant. So besides the testing equipment in the bid, much more construction facilities and tools were bought later according to the situation. These were bought in Hangzhou with an economic price and very functional.

The enough funds also make it possible for the staff employment and training. With professional staff, the establishment of the lab followed the plan and efficiently, which in turn ensure the normal operation after the establishment to serve teaching, research and engineering practice.

### **3) project application support**

The establishment and operation of the lab on the one hand provide support for the earth construction teaching and on the other hand function as a research platform for the project of Zhejiang local architectural resource survey. Besides, it also support technically for Prof. Wang Shu's rammed earth project. It is because of this feasibility, the establishment proceeded toward a good direction.

In fact, at the beginning of the preparation stage and before the full collaboration with CRATerre, for the reason of lack of professional staff and with no reference, the preparation for the lab had taken some wrong paths. For instance, when I chose the equipment and tools, I hadn't participated in the DSA program and taken reference from the equipment list of CRATerre. As a result, too many facilities were bought abroad and the prices were much higher than those domestic ones. In the future, the purchase of new facilities will first turn to the domestic ones with good quality in order to save cost.

As the first earth architecture lab, its establishment and operation will be a reference to the similar labs in China. In fact, the Architecture Department of Xi'an University of Architecture and Technology is planning to establish a lab of this kind with the promotion of its dean Prof. Mu Jun's. The establishing model and equipment are following our lab, which will help the success of the lab as much as possible.

Additionally, as for the core technologies of the lab, that is the soil identification, I will adjust the standards based on the *Soil Identification Manual* provided by CRATerre, taking into the consideration of the standards of China, in the hope of making better use of these standards in China.



## 3 夯土教学

可持续建造实验室建立的主要目的之一就是配合建造教学实践，为我院本土建筑学教学的开展提供坚实有力的技术支持。在建筑艺术系开设建造课程的教学目的在于让学生们通过动手操作，包括真实材料的建造与性能测试，帮助理解材料应用的原理及切实掌握材料应用的方法，进而能够自行设计材料的建造方式，从建造角度促进专业设计能力。此前，已开设的建造相关课程有木工基础、砌筑基础和金工基础。随着生土实验室的建立，夯土建造课程也得以系统科学地开展起来。

事实上，在实验室筹建之初，即 2010 年 6 月，我系即已尝试开展夯土建造课程，是为本文中记述的第一次夯土建造课程；在实验室进入实质性的建设阶段，即 2011 年 9 月，我系开展了第二次夯土建造课程；在实验室已基本建设到位后，即 2012 年 6 月，我系开展了第三次夯土建造课程。其中，第一次课程并未依托于实验室的技术支持，教学过程偏重于夯筑的建造设计和试验；第二、三次课程则较为全面涵盖了现代夯土建造的科学分析和建造技术。截止本文完成之日，第三次课程仍在进行中，因此本文将第二次课程作为记述的重点。

### 3.1 第一次夯土建造课程

课程时间：2010 年 5 月 31 日—7 月 2 日（5 周）

主讲教师：张雯

学生：一年级（建筑艺术系 09 级），共 61 人

#### 3.1.1 教学目的与内容

本次课程的教学目的首先在于让学生们了解生土建筑当今应用的意义，然后通过动手夯筑了解生土材料的性能，掌握基本的生土夯筑技术，从而理解版筑建造方式对建筑形式的影响，



第一次夯土建造课程施工现场

Building site of the first rammed earth course, 06/2010

### 3 Teaching on rammed earth

One of the main purposes of SCL is to support construction teachings of our school with its technology. The objective of the construction courses of Architecture Department is to encourage the students to understand the fundamentals and methods of material application and then have the capability to design construction ways with the material through practices with material constructions and tests so that their professional design skills would be improved. Before that, there had been courses of carpentry basis, masonry basis and metalworking basis. With the establishment of the lab, rammed earth courses are carried out systematically.

In fact, at the beginning of the preparation of the lab, namely in June 2010, the department had a rammed earth construction course, referred as the first rammed earth construction course in this thesis; in the establishing phase of the lab, namely in September 2011, there was the second one; after the basic establishment of the lab, namely in June 2012, there was a third one. The first one was not supported by the lab technically; the teaching had attached more importance to the construction design and experiment; the second and third ones have covered the modern rammed earth construction completely with scientific analysis and construction technology. Till the completion of this thesis, the third course is still under its way.

#### 3.1 Rammed earth course 1

Time: May 31, 2010—July 2, 2010 (five weeks)

Teacher: Zhang Wen

Students: First-year, 61 students

##### 3.1.1 Objective and content

The objective of this course first of all was to enable the students to know the significance of the application of earth today, and then know the property of earth materials through practices, acknowledge the basic rammed earth skills so that they can understand the influences of template construction to the building form and obtain the practical basis for the earth construction or even the variety of designs for template construction.

Therefore, the focus of the teaching was to make the students understand the construction process, on which basis to design the rammed earth wall structure and practice themselves to verify the designs. Finally every team finished a rammed earth wall of 3 meters long, 0.35 meter wide and 2.7 meters high, since it was team work, during the process, students could learn from each other in aspects of design, construction and effects.

##### 3.1.2 Teaching plan and process

According to the plan, the course was divided into three phases:

**The first phase, was theory lectures on earth architecture and rammed earth technology, site investigation and reference books reading, designs of the structure of the rammed earth wall.**

The result of this phase was to have every student make a drawing of the designed rammed earth wall with construction structure specifics based on the lectures, investigations and understanding of the rammed earth technology, the drawing should cover rammed earth tools, the section of the wall and

并为进行生土建造以至版筑建造的多样性设计打下良好的实践基础。

因此，教学的重点在于首先让学生们理解夯土的建造过程，在此基础上进行夯土墙施工构造的设计，然后通过动手实践来验证各自的构造设计。最终每组各完成一堵长  $\times$  宽  $\times$  高  $= 3\text{m} \times 0.35\text{m} \times 2.7\text{m}$  的夯土墙体的建造。由于是分小组工作，因此在整个过程中可以进行设计、施工和效果等各方面的相互比较学习。

#### 3.1.2 课程计划与实施

按照教学计划，课程大致分为三个阶段：

**第一阶段，生土建筑及夯土技术的理论授课、现场考察与文献阅读，夯土墙施工构造设计。**

这一阶段的成果即通过授课和调研，在理解夯土技术的基础上，每人设计一份夯土墙体施工构造图纸，内容包括：夯土工具、夯土墙剖面和施工技术详解。

在此期间，由施工队负责在场地上现浇 25cm 高钢筋混凝土墙脚三个。

**第二阶段，夯土实践，包括生土材料及附加材料、夯土工具的准备，试样制作和夯筑。**

从 61 份设计图纸中，选择出若干份有代表性的方案设计，进而整合出三个施工方案。将学生分成三大组，每组约 20 人，分别实施其中一个方案的夯土建造。三个施工方案主要从加强措施、外观效果和开窗方式进行区别：

第一组：加强措施：竹筋、杉木条、销键

外观：瓷片

开窗：开大窗

第二组：加强措施：麦秸

外观：不同色彩的土

开窗：不开窗

第三组：加强措施：沿高度方向改变土方配比

外观：分三个层次，每层之间加砌青砖一皮

开窗：后开窗

方案确定后，每组成员分工合作，先根据各自的施工方案，准备材料和工具。其中，三个组的夯土模板和夯锤是相同的，已在课程开始前由木工制作完成，为浙江地区传统的木模板和



左：学生们在校外采集土样；右：其中一组收集的土样

Left: Students were collecting the earth samples outside the campus (photography: unknown); Right: Earth samples of one team, 06/2010



elaboration of the construction technology.

During this period, the construction workers were charged of casting three reinforced concrete foundations of 25cm high on the site.

**The second phase, was ramming earth practice, including the preparation for earth materials, added materials, ramming tools, sample production and ramming.**

Chosen from the 61 pieces of drawings, the most representative proposals were combined into three construction schemes. The students were grouped into three teams with approximately 20 students a team, building the respectively scheme. The three schemes were differed from the enhanced measures, the appearances and the ways of opening windows:

Group 1: Enhanced measures: bamboo sticks, pinewood sticks and pin key

The appearance: ceramics

Window opening: big window

Group 2: Enhanced measures: wheat straw

The appearance: earth with various colors

Window opening: no window

Group 3: Enhanced measures: change the proportion of the earth mixture according to the height

The appearance: division of three layers, a layer of gray bricks were added into every two layers of the earth

Window opening: rear window



左：学生们自行采集的土料及其配料；右：课程使用的传统模板

Left: Earth and other material taken by the students; Right: Traditional formwork used in the course, 06/2010



木夯锤，模板的长 $\times$ 宽 $\times$ 高 $=2\text{m}\times0.35\text{m}\times0.33\text{m}$ 。在生土材料的选择和取用上，则各组自行决定。考虑到运输问题，多选在学校附近的工地、山坡等地，由学生们自行用铲子挖土，再雇佣小卡车运回场地，并做好防雨措施。

与此同时，部分学生按照施工方案分别进行 20cm 立方体夯土块试验，根据试验情况调整施工方案。还有部分同学则制定本组的夯筑分工计划表，包括采土、拌土、夯土、工具保管和记录等的分工和施工计划。这是因为在夯筑课程的同时，他们还同时进行砌筑课程，因此小组各成员必须合理安排好分工项目和工作时间。

当一切准备就绪，开始正式的夯土。施工期间，要求各组分别记录夯土过程，包括记录材料配比、施工工艺与进度和施工人员等，并拍摄过程照片。施工结束后，清理场地。

#### 第三阶段，课程成果整理和汇报，包括夯土过程记录、夯土经验总结和交流。

课程的最后，要求各组整理整个课程的过程记录，总结夯土经验，并进行汇报交流。通过对各组完成的夯土墙进行评估比较，如施工方法的合理性，墙体的稳定性、强度等，从实践中学习。

#### 3.1.3 教学成效与经验

这是我系头一次夯筑课程，学生们对夯土这一“新鲜”事物投入了很高的热情，顶着炎炎烈日辛苦劳作。由于三种施工方案、三种墙面效果在同一场地上并列呈现，三个组之间相互学习、



左：学生现场夯土；右：其中一组制作的试块

Left: Students were ramming earth on the site; Right: Rammed earth sample blocks of one team, 06/2010

After the scheme was set, every member in the teams got his/her own job. Firstly, prepare the materials and tools according to the construction schemes. It was noted that the formwork and rammer of each team were the same and had been produced before the course by a carpenter. They were the traditional wooden formwork and wooden rammer of Zhejiang area. The formwork was 2 meters long, 0.35 meter wide and 0.33 meter high. Every group made their own decisions on the option of earth material. In consideration of the problem of transportation, they mostly had chosen to fetch the earth on the construction site and hillside near the school. The students used shovels to dig and then transported it back to the site with a cart; they were also responsible to take measures for the rain-proof.

In the mean time, some students were doing tests on the earth cube of 20 cm according to their scheme and adjusted the construction scheme based on the test result. Some students were making the working schedule and distribution, including distribution on earth collection, mixing, ramming, tool keeping and recording and the construction plan. Because there was a masonry course at the same time, the team members had to well arrange the distribution and time of working.

When everything was ready, the ramming began. During the construction, every team was required to record the whole process of ramming, including the material proportion, construction craft and the procedure as well as the construction workers. Process photography was also required. After the construction, the students had to clean up the site.

**The third phase, was to sort out the course results and make presentation, including the process records, experience summary and exchanges.**

Finally, every team was required to review the records of the whole process and sum up their experience in ramming and make presentations to exchange. Learn from practice through comparison between the finished rammed earth walls of every team in aspects such as the reasonability of the construction methods, the stability and strength of the walls.

### **3.1.3 Effect and experience**

This was the first ramming course of our department. The students were inspired by this “new” event, working hard in the extremely hot sun. Since the three construction schemes, three kinds of walls were represented on the same site, the three teams learnt and competed from each other, the students’ skills in ramming were improved quickly. To the end of the five-week course, because of limited time and bad climate, the wall was only constructed to 1.4 meters high instead of 2.7 meters. However, every team basically realized the appearance of the walls and got to understand the features and possibilities of the template construction. It was regretful that the final presentation was not done because of the lagging of the construction phase. But every team submitted a report.

By summing up, apparently, the main problem of course was a lack of systematic and scientific probe into the material and the rammed earth technology, but mainly with experience and feelings. Therefore, though the supposed objective of the course was to get experience and cognition through the comparison of the three teams, so that the students would acquire the ramming skills, but in fact because of the lack of systematic and scientific theory support, it was impossible for them to understand and acknowledge the rammed earth construction totally with short working experience. It had to be acknowledged that this was largely due to my limited knowledge and experience in this

相互竞争，使得学生们的夯土技术在实践中快速提高。虽然直到五周课程结束，由于时间和天气因素，墙体未能夯至 2.7m 高，仅完成至约 1.4m，但各组基本上实现了墙面外观效果的尝试，理解了版筑建造的特点和可能性。遗憾的是，由于建造环节的拖延，最终未有时间进行公开的汇报环节，仅各组提交了课程报告文本。

如今回顾此次课程，很显然，课程存在的主要问题就是缺乏对生土材料、夯土技术系统的、科学性的探讨，很大程度仅停留在经验和感受上。因此，虽然课程的初衷是通过三组的比较来获取经验、提高认识，从而掌握夯土技术，但事实上由于缺乏系统的、科学的理论知识的支撑，仅凭短时的劳作经验，很难全面切实地达到理解和掌握夯土建造的目的。不得不承认，这主要是由于当时作为任课教师的我在此方面的知识和经验局限所限。

课程中，由于对适用于夯土的生土材料的选用缺乏正确的认识，因此学生们取来的土多为面层的种植土。虽然每堵墙均添加了加强材料，如木条、竹筋等，但这其实是对夯土技术的一种误解。实际情况是本地土质粘土含量高，未经砂石配比的夯土墙很快就产生了大量的裂缝。除了所取土的质量问题，由于自行取土花费了大量的时间，也使课程的进程受到了影响。

另一方面，由于使用的是传统木模板，在支模构造上的先天缺陷，导致版与版之间夯土面不够密实，甚至容易发生偏移。而由于木模板和木夯锤的制作质量不够高，致使施工中损坏，延误施工时间等现象时有发生。这些教训都是可以在今后的课程中避免的。

还有一个致使建造未能按期完工的重要影响因素则是天气。夯土本身已是一项艰苦的劳动，而在杭州六月下午的烈日下进行夯土户外作业，十分消耗体力，学生们则选择了推迟或减少劳动时间。此外，由于时值南方梅雨天气，雨水时常中断施工过程。



第一次夯土建造课程完成的三堵墙体  
Three walls built in the first rammed earth course, 09/2010



aspect as the teacher at that time.

In the course, the earth taken by the students was largely the surface earth for planting because of the little knowledge on the choice of earth material for rammed earth. Though every wall was added with enhancing materials such as wooden pieces, bamboo sticks etc. But this was a misunderstanding of rammed earth technology. The real situation was that the local earth had a high proportion of clay, with which the wall constructed without adding sand or gravel soon appeared a lot of cracks. Besides the problem of the earth quality, the self-fetch of earth had influenced the process of the course greatly.

On the other hand, since the formwork was traditional wooden one, a defect of supporting structurally was inevitable, which caused that the rammed earth between templates was not intense enough or even appeared malposition. Since the quality of the wooden formwork and rammer was not good enough, they were damaged in the construction, delays in construction often happened. These could be avoided in the future courses.

Another important factor for the delaying of the construction was the bad climate. Ramming is a tough work. In the June sun of Hangzhou, the extremely hot climate was so exhausting that the students chose to postpone the starting time or reduce the working time. Besides, it was the rainy season of southern China. The rain often stopped the construction process.

Additionally, problems such as the time for the course, number of participating students led to the difficulty of ensuring the participations of all students in the construction process and in turn affected the teaching effect. This problem was the inevitable in such rammed earth construction courses. This will be elaborated in the following part.

## **3.2 Rammed earth course 2**

Time: September 5, 2011—October 9, 2011

Teachers: Marc, Juliette, Zhang Wen

Students: Fourth-year students, altogether 41 students

### **3.2.1 the original plan**

According to Prof. Wang Shu, the original plan was to have a rammed earth workshop within five weeks. The fourth-year students were instructed to construct the rammed earth wall of 3.5 meters high for the metalworking lab(the building area is about 70m<sup>2</sup>).

The workshop was also a construction experiment for the rammed earth walls of the “Tiles Hill” project. The experiment included aspects of the proportion and preparation method of materials, formwork system and small scale of production line (that is excavation, preparation, transportation of earth and ramming); at the same time it also tried with different kinds of local earth to test the surface texture.

The course was planned to be in two phases: the first week was for the lectures on the earth materials and construction technology. The other four weeks were for construction. During the lecture week, we organized the site (cleaning up the site, wall base production), prepared the earth materials, formwork and tools.



除此之外，就是在课程的时间、人数等设置上的问题导致学生在整个夯土建筑中的参与度难以保证，也影响了教学效果。这一点是我系开展夯土建造课程难以回避的问题所在，将在下文中一并分析陈述。

## 3.2 第二次夯土建造课程

课程时间：2011 年 9 月 5 日—10 月 9 日

教师：Marc、Juliette、张雯

学生：四年级（建筑艺术系 08 级），共 41 人

### 3.2.1 课程原计划

王澍教授对本次课程的计划是，在 5 周时间内，开展一次夯土工作营，指导四年级学生建造金工实验室（建筑面积约 70 m<sup>2</sup>）的夯土墙，墙高 3.5m。

本次工作营亦作为“水岸山居”夯土墙体的建造试验，试验内容包括材料的配比与制备方法，模板系统，以及小型的建造流线（即采土、备土、运土和夯筑等的操作流线），同时亦尝试用当地不同的生土在夯土墙面上实现的肌理效果。

课程计划分为两个阶段：第 1 周进行生土材料和建造技术的理论与实践的授课，后 4 周实施建造。在第 1 周授课的同时，组织建造场地（包括清理场地、制备墙体基座），准备生土材料，以及模板和工具等。

### 3.2.2 实际的教学过程

#### 第一周，理论授课与练习。

讲座一：《生土建造与当代生土建筑》，介绍了生土建筑在世界范围内的重要性，关于为何跨越了时间和空间，全球的许多文明一致地选择了生土这种材料。此外，还介绍了生土在传统和当代建筑中的应用，借此引出生土主要的建造方式及其技术。



左：学生在实验室进行试验操作；右：教师现场示范野外测试

Left: Students were operating in the lab; Right: Teacher was demonstrating field tests on the site, 09/2011

### 3.2.2 Course process

#### The first week: theory lectures and exercise

Lecture 1: *Earth Construction and Contemporary earth architecture*, this lecture introduced to the earth architecture around the world, the reason why many civilizations around the world had chosen the material of earth, despite time and space. It also introduced to the application of earth in traditional and contemporary architecture and drew forth the main construction approaches and technologies.

Lecture 2: *Earth as a Construction Material*, it focused more on technologies, depicting the physical property and components of earth (grain distribution, clay, moisture, etc.) . It also introduced the rammed earth construction technology.

Practice: design a rammed earth production line. After the lectures, the students were asked to design a rammed earth production line for the preparation of the rammed earth wall for the metalworking lab. The practice was divided into three procedures. Firstly, the students discussed the main procedures (such as excavation and preparation of earth, ramming and so on) of the construction together under the instruction of teachers. After the class, the students were grouped into six teams and every team was to finish a pamphlet about production line design that was about the site organization and working line according to the building site. The line should be reasonable and efficient. Finally, the designs were accumulated and the teachers guided the students to finish a pamphlet about the optimal production line. This exercise helped the students understand fully how to organize effectively and would help greatly on the practices.

#### The second and third week, practice on the rammed earth production line

According to the original plan, from this week the students were supposed to start the rammed earth construction on the site. But because of some unexpected factors, the earth materials, base and formwork for the wall had not been prepared. So we organized another smaller line, using the recycled earth from the finished rammed earth wall last year and the same traditional formwork as the previous course.

The purpose of this was to construct a “teaching wall” to test the production line and for the students to experience the rammed earth technology. In the process of ramming, by using different proportion of earth, the students would experience the influences of the difference operations of procedure to the production line and the changes of the quality of the rammed earth wall.

#### The fourth week, the proportion test of the earth materials

In consideration that the metalworking lab hadn't been equipped with the relative constructing conditions, we then arranged a set of testing practice, which was carried out with three steps in the lab for the proportion test. The purpose of the practice was to make the students understand the composing grains of earth and the meaning of moisture, and obtain the method for material reformulation based on the analysis of the test result.

Step one, comparison test of the rammed effect of different proportions of earth. Ram different proportions of earth mixture in the moulds in order to understand the influences of various sizes of grains and their proportion to the ramming effect: the more the composing grains are, the more

讲座二：《生土作为一种建筑材料》，偏重于技术层面，讲述了生土的物理性质和组成（颗粒分布、粘土、水分等）。此外，着重介绍了夯土建造技术。

练习：设计夯土建造流线。在理论授课之后，让学生进行夯土建造流线的设计练习，作为金工实验室夯土墙建造的准备。本练习分三个步骤来完成，首先在课堂上，学生们在教师的引导下共同讨论了夯土建造的各个主要步骤（如采土、备土和夯筑等）；课后，学生共分成6组，各完成一份建造流线设计文本，即关于本次课程夯土作业的场地组织与工作流程，要求作业流线合理，人员高效作业；最后，将学生们的成果讨论汇总，在教师的指导下，共同完成一份最优化的建造流线文本。这项练习有助于学生们充分理解如何对场地及施工进行有效的组织，对实际的夯土作业有极大的帮助。

### 第二、三周，夯土建造流线实践。

按原计划，这周开始学生们应该在场地上实际开展金工实验室的夯土建造。但由于某些不可控的因素，用于金工实验室的生土材料、墙体基座和模板一直没能如期备好。因此，我们组织了一条小型的夯土建造流线，使用的是去年夯土课程建成的夯土墙的回收土，和同样是为上次课程制作的传统夯土模板。

这项练习的目的在于建造一堵“教学墙”来检验建造流线，并让学生们体验夯土技术。夯土过程中，通过不同配比的生土的使用，让学生们体会不同的操作流程对建造流线的影 响，以及夯土墙质量的变化。

### 第四周，生土材料的配比试验。

鉴于金工实验室仍未具备建造条件，我们于是设置了一套试验练习，在实验室里分三个步骤进行土的配比试验。这项练习的目的在于通过一系列的比较试验，让学生们理解生土的颗粒组成及其含水率的意义，掌握在对测试结果分析的基础上的材料配比的方法。

第一步，不同配比土的夯实效果比较试验。在模具内夯实不同砂石配比的混合土，从而理解不同尺寸的颗粒及其比例对夯实效果的影响：当颗粒的组成越丰富，夯土越密实。

第二步，不同含水率的夯实效果比较试验。以第一步试验得到的最佳颗粒组成的土样，进行 proctor 击实试验，从而理解不同的含水率对夯实效果的影响：含水率存在一个最佳值，此时的夯土最密实。



学生在教师指导下完成的部分夯土建造流线设计图纸

Part of the drawings of rammed earth production line made by the students, 09/2011

compacted the rammed earth will be.

Step two, the comparison test of rammed effect of different water content. The optimal earth proportion gained from the first step was used to do the proctor test in order to understand the influences of different water content to the rammed effect: there exists an optimal water content, with which the rammed earth is compacted best.

Step three, check the calculated result of the proportion by sieving test. Let the students sieve the local earth, sand and gravel and draw the grain-size distribution curves. Then calculate the proportion based on this test result and get the suitable proportion of the mixture with earth, sand and gravel. Compare this proportion with the optimal proportion gained from step one. Additionally, let the students sieve the earth mixture according to this proportion and compared the result of the sieving test with the one of grain proportion calculation.

### The fifth week, earth construction

In the construction workshop, the columns and base of the rammed earth wall were produced with earth mortar and gray bricks. The purpose of this practice was to enable the students to obtain the masonry technology of earth mortar and prepare for the experimental rammed earth wall that would be built in the construction workshop.

#### 3.2.3 Effect and experience

As mentioned above, the course was original planned as a construction course, the focus of which was construction practice. But the real situation was, the course didn't finish the construction mission according to the plan because of the bad preparation of various aspects. Instead the students experience and learn the property of earth and rammed earth technologies through a series of practices and lab tests.

The course was taught from three forms: theory lectures, experiments and construction practice. The theory lectures involved aspects of earth architecture, earth materials and earth construction technologies. The experiments were consisted of five hydrous forms of earth experiment, comparison test of compaction, optimal water content test and the calculation of grain proportion. The construction practice included the design of production line, ramming of the "teaching wall", masonry work of the base and columns. Objectively, as an earth course, the adjustment of the content and



左：学生们在进行筛分测试；右：学生们砌筑夯土墙基座

Left: Students were doing sieving test; Right: Students were making the base of the rammed earth wall, 09/2011



第三步，用筛分法检验配比计算试验的成果。先让学生筛分当地的土、砂和石，分别绘出粒径分布曲线，再根据此测试结果进行配比计算，求出适用于夯土的混合土的土砂石比例，并将此比例与第一步试验的最佳配比土进行比较。另外，按此计算比例混合后，再让学生筛分此混合土，将筛分测试的结果与颗粒配比计算的结果进行比较。

#### 第五周，生土建造实践。

在建造工作坊里，用生土砂浆和青砖砌筑柱子和夯土墙的基座。这项练习的目的在于让学生掌握生土砂浆的砌筑技术，并为将在建造工作坊内进行的试验夯土墙做准备。

#### 3.2.3 教学成效与经验

如上所述，本次课程原是一次建造课程，侧重于建造的实践。但实际情况是，由于各项准备工作不到位，致使课程未能按计划完成建造任务，学生们更多地是通过一系列的实践练习和实验室试验来体验和学习生土的性能和夯土技术。

课程通过理论授课、实验操作和建造实践三种教学形式开展。其中，理论授课的内容包括生土建筑、生土材料及生土建造技术三方面；实验操作的内容包括生土的五种含水形态试验、夯实比较试验、最佳含水率测试和颗粒配比计算；建造实践的内容包括设计建造流线、夯筑“教学墙”、砌筑砖基座和砖柱。客观地说，这一课程内容和设置的调整，就生土教学而言，应更有利于学生对夯土的材料及其建造的学习。尤其在使用传统技术的夯筑教学过程中，未经配比的材料、传统的支模方式，都使得土墙夯筑质量不高，但学生们也恰恰从失败中学习，更加深切地理解现代夯土技术，体会到技术改进的必要性。这样的夯土墙虽不完美，但也因此称得上



学生们夯筑的“教学墙”

The "teaching wall" built by the students, 09/2011

setup of the course should have been better for the students to learn rammed earth material and its construction. Especially in the teaching process of using traditional technology, the materials without proportion and the traditional way of formwork installation resulted in the bad quality of the rammed earth wall. But the students also learnt from the failure, understood more of the modern ramming technology and the necessity to improve the technology. The wall was not perfect, but it could be said that it was a true “teaching wall”.

Although the course had been adjusted on time and with good reasons, with restrictions such as materials, tools, time, number of students, the supposed teaching effect was not achieved fully. The problems this time were similar with the first course and were the ones the third one was going to face:

### 1) preparation

The site, materials and tools are the presupposition condition for any kind of construction course. The course, as the experimental workshop for the “Tiles Hill” project, the construction materials needed such as earth, sand and gravel as well as the formwork and base of the wall should be provided by the construction corps of the project. But in fact, about one third of the construction material didn’t arrive until the end of the third week and the concrete base of the wall was only finished until the fourth week; the formwork was installed on the last day of the course. The lagging of preparation on the one hand was because of the negative working attitude of the corps who was always late of doing the job; on the other side, it was the first time that the corps being commissioned with a rammed earth project. They doubt of every step such as the design and production of formwork, the choice of earth and the proportion and so on. This was why the preparation was so lagged behind.

Fortunately, all the tools and facilities for earth tests and construction have all been fixed. The only difficulty is the material preparation for the future rammed earth courses, because in China, earth is not a common construction material that could be bought directly. When it is required to use large quantity of earth for construction, we have to turn to other access.

### 2) time for teaching

The time for this kind of workshop is the same as the other design courses—in the morning or afternoon of every Monday, Wednesday and Friday, that is, three times a week and three hours one time. It could be imaged that such time arrangement is very unfavourable to construction work and especially affect the rammed earth construction. Since as soon as the production line starts, three



第二次课程的夯土现场  
Building site of rammed earth course 2, 10/2011



是一堵真正意义上的“教学墙”。

虽然课程的调整及时合理，但由于材料工具、课程时间、学生人数等客观条件的因素，未能完全达到预期的教学效果。这些问题与第一次课程所遇到的问题是类似的，也将是第三次课程要面临的问题：

#### 1) 准备工作

对任何建造课程而言，具备场地、材料和工具是前提条件。这次课程作为“水岸山居”项目的试验工作营，建造所需的土、砂、石等建筑材料，以及模板和墙体基座的制备都由负责该项目建造的施工队提供。但事实是，约 1/3 的建造材料在第 3 周末才送到，混凝土基座到第 4 周才完成浇筑，模板则是在课程的最后一天搭建完毕。准备工作的拖延，一方面是由于施工队没有积极地配合我们的工作，经常延误；另一方面也因为施工队是首次接手夯土工程，对各个环节常心存疑虑，如模板的设计和制作，生土材料的选用和配比等，因此也造成了准备工作的一再滞后。

值得庆幸的是，如今可持续建造实验室的生土测试和建造的工具设备都已到位，今后的夯土课程，唯独可能在生土的材料准备上比较困难。因为在这里，生土并不是一种可以直接购买的建筑材料，因此当需要大量生土用于建造时，必须另找途径。

#### 2) 教学时间

建造课程与其他专业课程一样，上课时间为每周一、三、五的上午（或下午），即一周三次课程，每次 3 小时。可想而知，这样断续的时间设置对建造工作而言是十分不利的，对夯土



课程结束时，由工人们施工的金工实验室夯土现场

Status of the building site of the metalworking lab made by the workers when the course was over, 10/2011

hours every time is too low efficient.

In fact, in the practice step, the six teams of students were purposely divided into two groups and took turns to join the workshop so that the time for working could be lasting. But this is apparently not a good solution yet, because to every student the time for the practice operation was not continuous and the learning outcome would be discounted.

### **3) number of students**

As mentioned above, the shift of times for the two groups of students, on the one hand was for the continuity of the construction work, on the other hand was because of the number of students. There were 41 students participating the workshop. If all of them had practiced at the same time, there were not enough materials and tools and no site big enough either. What's more, it would be difficult to organize the workshop on site. The result would be unsatisfactory. Therefore, taking turns was a solution with no other alternative. But this definitely increased the working hours of the teachers greatly.

As a matter of fact, for the reason of the lagging behind of the construction of the rammed earth wall for the metalworking lab, the teaching plan had to be adjusted again and again. The students were doubt of the feasibility of the rammed earth construction. Fortunately, one fourth of the students had shown interest in the learning of rammed earth and devoted themselves to it.

### **3.3 Feedback**

In addition that the teachers should sum up the teaching process and experience gained, they should also get to know the real effect from the students' perspective. Especially for this purpose, a "Rammed Earth Construction Course Questionnaire" was designed to make a survey of the students who attended these two rammed earth courses as a feedback resource. (Appendix: questionnaire)

The questionnaire tries to get feedback from three aspects: teaching effect, course arrangement and earth architecture as a profession. Thus in addition to teaching, the survey also pays attention to the view point of students of architecture major toward earth architecture, getting to know the possibilities of their future career.

The questionnaire is consisted mainly with choices, including single choice and multiple choices complemented with several questions in order to know the reasons for the choices. Students involved in the survey are the ones who have participated the first and second rammed earth construction courses. And the survey was done in class anonymously in April 2012, two years after the end of the first construction course and half a year after the second one. It is just because of this apart of time that the students could reflect calmly and objectively. It is regretful that many students of the four-year students who have participated the second course have not been included in the survey because of their internship out of campus. But it is still possible to reflect the learning conditions of the students from the result of the survey. (Appendix: statistics of the survey)

From the teaching effect, most students don't know much about earth architecture or rammed earth construction before the courses. But they have the willingness to learn. The reason that the courses didn't meet their expectations fully is mainly because of the set of the courses that I have mentioned above. Although the effect does not fully achieve the expectation, it is relieved that through the



建造的影响尤甚。因为夯土建造流线一旦运作，每次只持续三个小时，效率太低。

事实上，在这次课程的实践环节，有意将 6 组学生分成两批，错开上课时间，有利于工作的延续性。但这显然也不是一个很好的解决方式，因为对学生个人而言，实践操作的时间仍是断续的，学习效果也打了折扣。

### 3) 学生人数

以上提到的错开上课时间，一方面是为了保证建造工作的延续性，另一方面则是考虑到学生人数的问题。参加此次课程的学生共 41 人，若要同时进行操作实践，一来没有足够的材料和工具，二来没有足够的场地，三来难以组织现场教学，影响现场授课的效果。因此，错开上课时间是一个不得已的解决方式，而这无疑大大增加了教师的工作量。

事实上，由于金工实验室夯土墙的建造一拖再拖，教学计划一再调整，使得学生对夯土建造的实际可行性也产生一定的怀疑。幸运的是，仍有四分之一的学生对夯土表现出了学习兴趣，并且积极投入到各项练习中。

## 3.3 教学反馈

除了作为教师应对教学过程进行经验总结外，还应从学生的角度了解教学的实际效果。为此，特对上过这两次夯筑课程的学生进行问卷调查，通过填写“夯土建造课程调查表”，作为教学的反馈。

调查表的制定试图从三个方面进行调查反馈，一是关于教学效果，二是关于课程设置，三是关于生土事业。因为此调查除了用以改进教学外，还关注建筑专业的学生对生土建筑的观点，了解他们在此方面的发展可能性。（附录：夯土建造课程调查表）

问卷的主要形式为选择题，单选或多选，辅以部分的问答，用以具体了解选项的原因。参与问卷调查的学生分别为参加过第一次夯土建造课程的 09 级学生，和参加过第二次课程的 08 级学生，采取的是在课堂上以匿名的方式独立填写。调查时间为 2012 年 4 月份，距第一次课程结束已近 2 年，距第二次课程也已半年多。但也正因为这一段时间的距离，学生们能够更加冷静客观地进行反思。但遗憾的是，由于正值 08 级四年级学生的实习期，因此并非所有课程学生均参加了调查，但还是能够从调查的统计结果中反映出学生的学习状况。（附录：课程调查统计）

从教学效果来看，大多数学生开课前对生土建筑或夯土建造不了解，但有学习的愿望，课程的教学基本但不完全达到他们的期望，究其原因，主要在课程设置方面，基本上在我上文中的经验教训中均已涉及。虽然教学效果未完全达到预期，但令人欣慰的是，通过课程，几乎所有学生都表示对生土建筑或夯土建造感兴趣，并对他们的专业学习有所帮助。将来有机会的话，他们还愿意更加深入地学习相关知识和技术。

在课程设置方面，大部分学生表示建造实践对他们的帮助最大，但对理论授课则相对兴趣不大。当然，也有部分学生表示出对理论授课和实验操作的学习兴趣。有意思的是，从统计结果来看，参加了第一次课程的学生，相对于参加第二次课程的学生，课程结束后对生土建筑或夯土建造的兴趣更大，认为对专业学习的帮助也更大，这一结果应该与他们参与建造实践的程度有直接关系。

courses, almost all students have shown some interest in the earth architecture or rammed earth construction and felt it is helpful to their professional study. If there is any opportunity in the future, they are willing to learn the relative knowledge and technologies more deeply.

In the setting up of the courses, most students said that the construction practice was most helpful to them, but the theory lectures were not so interesting for them. Of course, some students also showed their interest in the lectures and testing operations. It was interesting that from the statistic result, the students who had participated the first course showed more interest in the earth architecture or rammed earth construction than the students of the second course did, and considered the greater help of the course to their professional study. This result should be related with the degree they were involved in the construction practice.

According to the previous teaching experience, it conforms to the features of the students in art schools. They are better at learning from practice instead of sitting in a classroom and listening to the lectures. They tend to be less interested in the experiments that require rational thinking and strict operation. In fact, in the first course, there was no experimental operation truly. But there were more such operations in the second one. The statistic result shows that the more experimental operations, the less they are interested in. But it also shows that the more experimental operations there are, the more the students feel their importance.

It reminds us that it is only that we make adjustment to the theory lectures, experimental operations and construction practices in order to make reasonable time distribution and interval arrangement, then it is possible to inspire the interest of the students in learning more efficiently. With the interconnection of the three aspects, the teaching objective will be achieved. For this purpose, we have already adjusted the teaching plan for the third construction course accordingly, in the hope of getting improved results in the future feedback survey.

In the survey of their willingness in participation of work on earth architecture in the future, it could be seen that most students are willing to do so; as architect, they will also be willing to use earth according to the situation. To sum up, there are three reasons: the advantages of earth buildings, such as ecologically sustainable; the local features of earth buildings that requires to be inherited; earth as a “new” material has the potential to apply in design. It could also be traced the education of contemporary local architecture of our school being reflected on the students. Although according to the survey, few students don’t want to be involved in relative work, but as architect, most of them will be willing to use earth according to the situation. It is also interesting that those students who participated the first course are more willing to do so while the students of the second course tend to choose more “rationally”. Is it because the more the students learn, the more restrictions they know or because of the different grades, experiences? There is no answer for this. But as users, most of them accept or even would like to live or work in earth buildings for a long time. However, the number of students who wouldn’t like to do so almost equals to those who would like very much, both about one quarter.

### **3.4 Rammed earth course 3**

Time: May 28, 2012-June 29, 2012(five weeks)

Teachers: Wang Shu, Zhang Wen, Chen Lichao

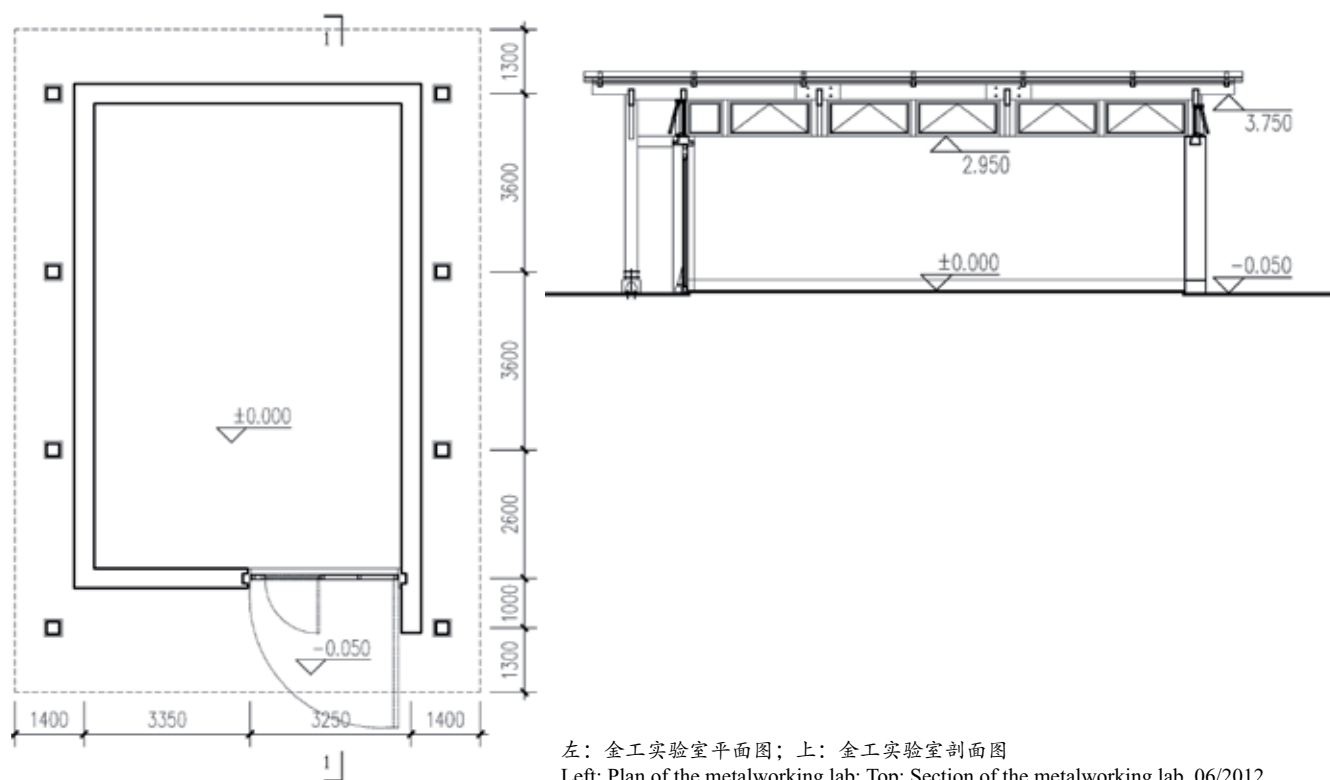
根据以往的教学经验,这是符合美院学生的特点的,他们更擅长于从实践中学习,而不喜欢端坐在教室里听课,对于需要理性思考、严谨操作的试验也比较不感兴趣。事实上,第一次课程并未进行实质上的试验操作,而第二次课程则较多,而统计结果恰恰显示出,越多的试验操作,学生们对此则越不感兴趣;但同时也显示出,越多的试验操作,学生们越能体会到其重要性。

这提示我们,只有将理论授课、实验操作和建造实践三个教学环节的教学方法改进,课时分配及其穿插安排更加合理,才能更有效地激发学生的学习兴趣,三者相辅相成,达到教学目的。为此,我们已对第三次课程的教学安排有针对性地进行调整,希望于日后的调查反馈中看到改进的效果。

在对未来从事生土建筑工作意愿的调查中,可以看到大部分学生愿意将来从事相关工作,作为建筑师,也愿意根据情况使用生土。总结起来,原因无外乎三种:一是生土建筑本身的优越性,如生态可持续;二是生土建筑的本土特征,需要传承;三是生土是一种“新”材料,具备设计应用上的潜力。由此也可见我院当代本土建筑学的教育在学生们身上的反映。尽管调查显示仍有少数学生不想从事相关工作,但作为建筑师他们大多仍会根据情况使用生土。还有个有意思的现象,即调查显示,参加了第一次课程的学生从事生土工作的意愿更加强烈,而相对地,参加了第二次课程的学生的选择则较为“理性”。这一差别是否是因为学的知识越多反而知道局限越多,还是因为学生年级、阅历不同导致的差别,我们不得而知。而作为使用者时,他们大多能够接受、甚至乐意长期居住或工作于生土建筑中,但不愿意的和很愿意的人数几乎相等,约 1/4。

### 3.4 第三次夯土建造课程

课程时间:2012年5月28日—6月29日(5周)



Students: first-year students, altogether 62 students

### 3.4.1 Task

According to Prof. Wang Shu, the planned task for this course is to finish the construction of the metalworking lab, including the whole building envelop of the walls, roof and the windows and door.

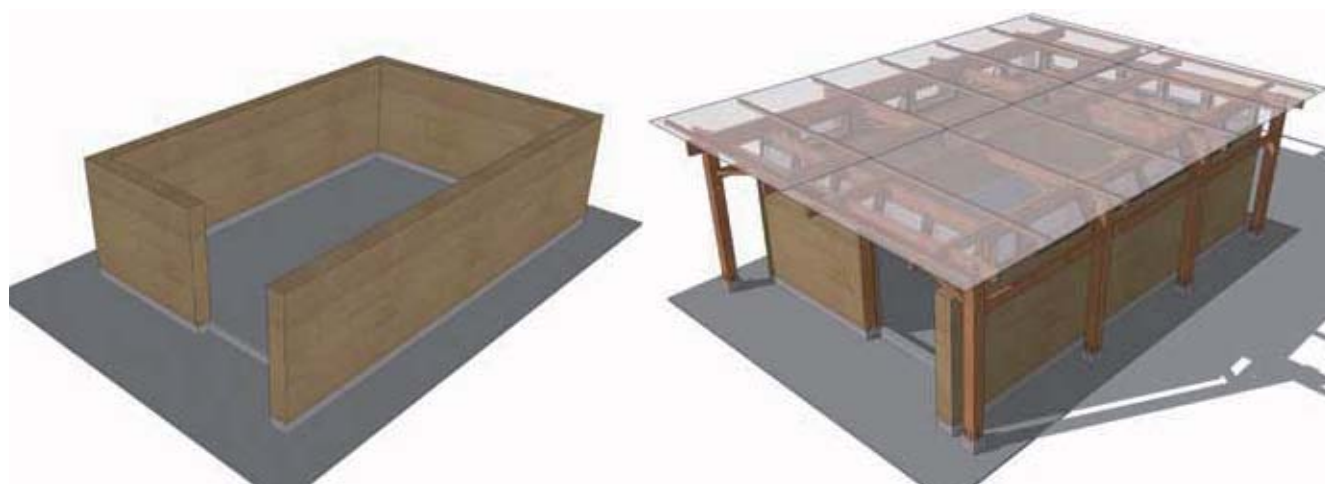
In fact, the rammed earth walls of the lab were planned to be finished in the second course. But finally the construction had continued after the course by the construction corps under the technical instruction of SCL. Due to the reason that the corps did not followed exactly the technical requirement on the preparation of the earth, the quality did not meet the same standard as the experiment done for the “Tiles Hill” project, the construction stopped at a height of about 2.4 meters. So in this course, it is planned to continue the construction of the walls to the height of 3 meters.

Besides, a wooden structure independent from the rammed earth walls will support the roof. So the linking structure of the wooden frame, the windows and door with the rammed earth walls will be paid attention to. The lab will be used after the completion of construction, so water draining, thermal insulation, ventilation and so on have to be well done.

### 3.4.2 Arrangement of the course

From the previous teaching experience, this course has to be prepared one month earlier. Firstly, produce the architectural working drawing according to Prof. Wang Shu’s design and prepare materials, tools and construction staff based on the design.

In consideration of the still existed problems such as the distributed time and too many students, the focus of the course puts on the lab teaching of rammed earth. The construction on site will be mainly conducted by the workers and assisted by the students, except for the part of ramming earth that will be conducted by the students. Therefore, the main task of the students is to experience construction and increase ramming skills through a series of experimental wall constructions in the lab. Theory lectures and test operations will be intervened to further increase knowledge and skills on rammed earth. Besides, the students will acquire the material linking structure and construction technology relative with rammed earth by constructions on site and practice their skills. Such arrangement will ensure the construction conducted by the workers won’t stop time to time and will finish on time so



金工实验室效果图，左：夯土墙体；右：木结构支撑阳光板屋面

Renderings of the metalworking lab, Left: Rammed earth walls; Right: Wooden structure supporting the roof made of polycarbonate sheet (designed by Wang Shu, sketched by Chen Lichao), 06/2012



主讲教师：王澍、张雯、陈立超

学生：一年级（建筑艺术系 11 级），共 62 人

### 3.4.1 课程任务

王澍教授对本次课程提出的计划任务是，完成金工实验室的建造，包括墙体、屋顶和门窗等所有围护结构。

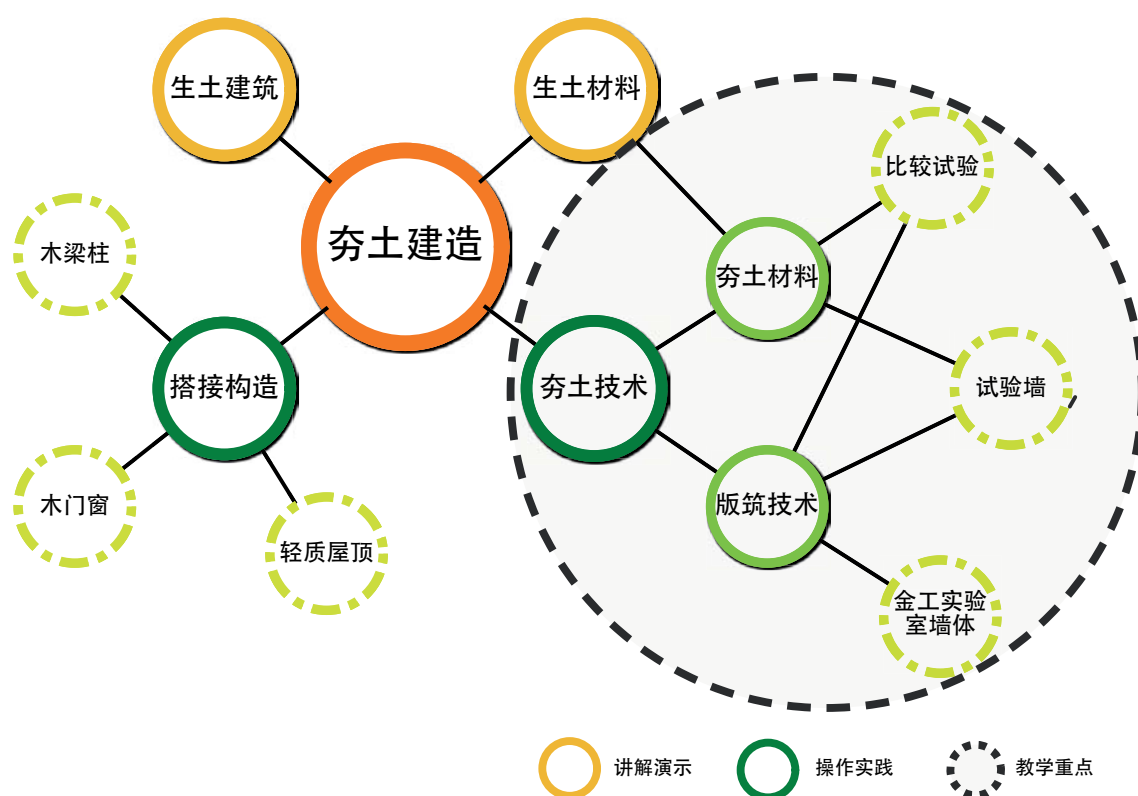
其中，金工实验室夯土墙原计划在第二次课程中完成，但最终是在课程结束后由施工队在可持续建造实验室的技术指导下继续施工。由于未严格遵循备土的技术要求，夯土质量未达到“水岸山居”夯土的试验标准，因而夯至高度 2.4m 左右时停工。这次的课程任务将在此基础上继续夯至 3.0m 高。

此外，将以独立于夯土墙の木构架支撑屋顶，注意木构架、门窗与夯土墙的连接构造。由于建成后将投入实际使用，因此建筑的各构造措施如排水、保温隔热和通风等都应做到位。

### 3.4.2 课程安排

根据以往的教学经验，此次课程提前一个月就开始了准备工作。首先按照王澍教授的设计绘制建筑施工图，根据设计准备材料、工具，安排好施工人员。

考虑到仍旧存在的课程时间不集中和学生人数多的问题，此次课程将教学的重点放在夯土的实验室教学。现场的施工，除工作量所剩不大的夯土由学生主导外，其余的建造主要由工人主导、学生辅助。因此，学生的主要任务是通过实验室的一系列试验墙体的建造来体验并提高夯筑技术，期间穿插理论授课和试验操作来加深理解夯土的知识和技术，并通过现场建造来实



课程教学主题

that the students will keep the pace with the construction process within the time of the course. From studying, observation and practice, the students will comprehend aspects of construction and leave enough time for the learning of rammed earth systematically. Thus, the teaching process is divided into five steps:

### Step 1, introduction to rammed earth construction

The students will get to know briefly the earth architecture and rammed earth construction by lectures and field trip to the ramming site; they will also be required to design the rammed earth production line on the site of the metalworking lab.

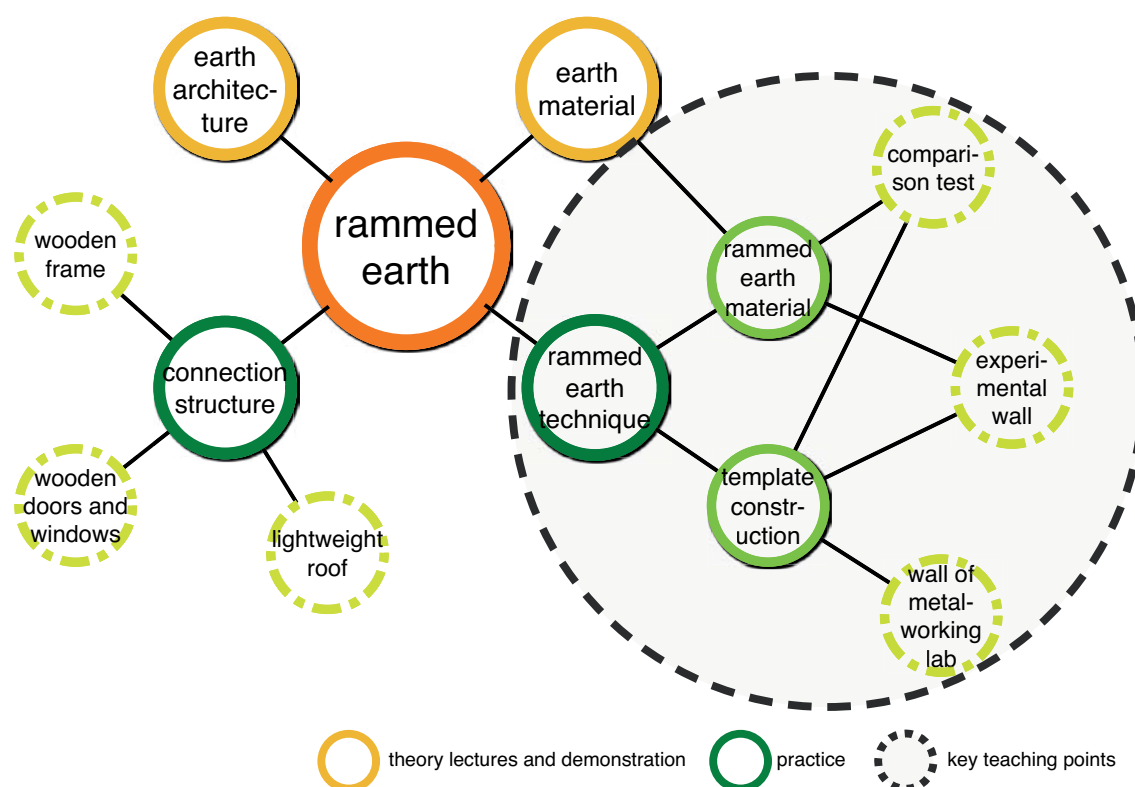
### Step 2, elementary rammed earth construction

Besides rammed earth construction on site, the students will do experimental construction of the rammed earth wall in the lab. There are three such walls, using pure earth, earth and gravel with a proportion of 3:1, and earth, sand and gravel with a proportion of 3:2:1 respectively. Traditional wooden formwork and wooden rammer will be used for the ramming.

The construction of these experimental walls on the one hand will solve the problem that there are too many students to work at the same time on site; on the other hand through such construction, the students will have the opportunity to experience the traditional ramming technology and observe how the different material proportions effect the quality of the walls.

### Step 3, to prove the rammed earth technology and its principle by testing

The series technical problems encountered in step two will be understood and solved in this step through comparison tests. This step will be consisted of three testing operations: 1) granular



## TEACHING TOPICS

践夯土技术，同时了解与夯土有关的材料搭接构造和施工技术。这样的课程安排，可以保证场地上由工人主导的施工不间断，按期完成建造，从而让学生在课程时间内能够全程跟进施工进度，通过学习、观察和实践全面了解建造的方方面面，同时也能留出足够的时间保证夯土学习的系统性。为此，教学过程计划分五个步骤进行：

#### 第一步，初识夯土建造。

通过理论授课和夯土工地的参观考察，让学生们初步了解生土建筑和夯土建造，并进行金工实验室施工现场夯土建造流线的设计。

#### 第二步，初试夯土建造。

除了现场的夯土施工外，学生们将在实验室进行夯土墙的试验性建造。试验墙夯三堵，分别使用纯土、土石比例 3:1 的混合土和土砂石比例 3:2:1 的混合土，以及传统的木模板和木夯锤进行夯筑。

试验墙体的建造，一来解决学生人数多，无法同时在现场工作的问题；二来通过试验建造，体验传统的夯筑技术，观察不同材料配比的土墙质量的差别。

#### 第三步，试验论证夯土技术及其原理。

在初试夯筑中遇到的一系列技术问题，将在此环节中通过比较试验来帮助理解，并思考问题解决的方法。这一阶段将进行三项试验操作：1) 颗粒配比比较试验，通过同体积的不同混合土在  $20\text{cm} \times 20\text{cm} \times 20\text{cm}$  的模具中夯实，观察试块的体积变化，比较颗粒比对土料压实程度的影响；2) Proctor 击实比较试验，相同的混合土，加入不同的水分后分别以标准击实仪击实，



试验墙 1 的建造现场，13# 楼生土建筑实验室外  
Building site of experimental wall 1, outside the SCL of Building 13#, 06/2012

proportion comparison test that the same volume earth mixture with different granular proportions shall be rammed in models of  $20\text{cm} \times 20\text{cm} \times 20\text{cm}$  to observe the influence of proportions to the degree of compaction by comparing the volume change; 2) proctor compaction comparison test that the same earth mixture with different water content shall be hit by the standard proctor tool respectively to realize the largest weight of the tested blocks to understand the concept of optimal water content; 3) layered compaction comparison test that the same earth mixture with the same water content shall be rammed in models of  $10\text{cm} \times 10\text{cm} \times 20\text{cm}$  with different layers to observe the compaction effect by comparing the weight of the tested blocks.

The three tests above have been chosen from the perspective of rammed earth construction technology. Strictly speaking, they are not material analysis tests. Besides, the choice is also made based on the characteristics that the CAA students are better at doing than at serious test and analysis. Through these simplified test operations, the students will be able to observe intuitively so that they can understand the principles and key points of the critical technology in rammed earth construction, namely, the correct proportion, suitable water content and layered ramming.

Based on the self-making tests and with theory lectures and demonstration, the students will further understand earth materials property and rammed earth technology.

#### Step 4, rammed earth construction once more

Based on the understanding of rammed earth technology and principles, the students will be required to do another experimental ramming construction of high quality in correct ways, with correct proportional earth, new formwork and pneumatic rammer. With guarantee of the quality of the walls, attempts and creations of the form, surface color and texture could be implemented according to the site.

After the two times construction of the experimental walls, the students will acquire conceptual knowledge from the perceptual experience of the rammed earth construction and will be able to



完工后的试验墙 1：学生们从建造的各个环节中总结经验和教训，为后续的教学提供基础

Completed experimental wall 1: the students had a lot of lesson and experience during the construction process, 06/2012



以实现试块的最大质量,理解最佳含水率的概念;3) 分层夯实比较试验,相同的混合土及其含水率,当分不同的层数在  $10\text{cm} \times 10\text{cm} \times 20\text{cm}$  的模具内夯实,通过比较试块的质量来观察不同层数的夯实效果。

以上三个试验的选择针对于夯土建造技术,并非严格意义上的材料分析试验。这同时是考虑到美院学生擅动手但不好严谨的试验和分析,因此通过这些简化了的试验操作,学生们可以直观地观察,从而理解夯土建造中关键技术的原理和要点,即合理的颗粒配比、适当的加水量和分层夯筑。

在学生们自行动手试验的基础上,结合生土材料和夯土建造的理论授课和示范演示,进一步加深对材料性质及建造技术的理解。

#### **第四步,再试夯土建造。**

在理解夯土技术与原理的基础上,要求学生们使用正确的方法进行高质量的夯土建造,使用合理配比的混合土,以及新式模板和气动夯锤。在保证墙体质量的前提下,还可结合场地进行墙体形式、表面色彩肌理等的尝试和创作。

经过前、后两次试验墙的建造,学生们将对夯土建造由感性的体验上升到理性的认识,并在掌握技术原理的前提下,进行再创作。配合同时进行的金工实验室的施工,学生们将了解夯土在建筑中的完整应用。

#### **第五步,总结夯土建造。**

课程的最后,要求将每一阶段的记录和总结文本汇编,形成最终的文本成果。除了以上所述各步骤的内容,还将包括金工实验室施工的过程记录和问题总结。

需要指出的是,本次课程分组进行,在各个教学环节中均以组为单位完成各项任务。尤其在建造和试验环节,各组学生需错开时间段,轮换场地和项目进行工作。幸运的是,本次课程的学生将于课程第一周的周末完成期末考试,这意味着在课程的第二周至第五周,除了周一、三、五下午的正常上课时间,学生们还有可支配时间自行安排建造、试验等耗时的工作,很大程度上弥补了课程时间短促和断续的不足,使这一教学计划得以更好地实施。

### **3.4.3 教学成效与经验**

从前两次课程结束后学生的反馈来看,学生对课程最大的不满在于始终未能完成建造计划,这意味着实践机会不够,且未能体验最终成果。此外,为了完成建造目的,而忽略学生个体的系统学习,也是学生对教学效果不满的所在。

如何在美院的课程时间体制下(我系一年级的建造课程,课程时间受到其他课程的限制,无法调整),合理组织 60 来个学生的建造课程,达到理想的教学效果,的确是一个挑战。因此,本次课程调整教学重点,注重课程的完整性和完成度,即学生们除了统一的理论学习外,在时间有限、资源有限的条件下,人人都能切实、系统地参加试验和建造,并能够参与到真实施工的现场,完成作品。唯有学生在完整理解生土建筑和夯土建造的基础上,才能在今后的专业学习或工作中真正体现此课程的价值。

截止本文完成之日,该课程仍未结束。但从刚刚完成的试验墙 1——初试夯土建造这一环节来看,完满地达到了阶段的教学效果。学生们在 7 天的时间里,进行了传统夯土技术的摸

recreate with the acknowledgement of the technical principles. With the simultaneous construction metalworking lab, the students will know the complete application of rammed earth in architecture.

### Step 5, conclusion of the construction

For the final step, the students are required to make a catalogue with the records of every step and the conclusion for the course. Besides all the contents of the previous steps, the catalogue will also include records of the construction process of the metalworking lab and problems accumulated from the process.

It has to be pointed out that the course will be progressed with group divisions of the students. Every step will be done by the students as groups. Especially for the construction and testing steps, every group of students has to stagger time, or shift sites and projects. Fortunately, the students will finish their final examinations of the other courses by the end of the first week of this course, which means from the second week, they can assign their time freely for the time-consuming tasks such as construction and testing besides the participation of the course every Monday, Wednesday and Friday afternoons. This will to a large extent complement the shortage and uncontinuity of time so that the teaching plan will be better implemented.

### 3.4.3 Effect and experience

From the feedback from the students of the two previous courses, the students were mostly unsatisfied with the incompleteness of the construction plan, which means they hadn't got enough opportunities to practice and didn't experience the final result. Besides, in order to complete the construction task, the students didn't learn systematically as an individual, which was the point of the students are dissatisfied with.

How to organize a construction course of more than 60 students under the course arrangement framework of CAA(the construction course for the first-year students in our department is restricted by the time schedule of the other parallel courses, so no adjustment can be made) to achieve the supposed teaching effect is really challenging. Therefore, the key points of this course have been adjusted, focusing more on the integrity and completeness of the course, that is, besides the theory



课程的第三阶段，左：学生们在材料分析实验室做比较试验；右：其中一组高质量的颗粒配比比较试验的试件

Third phase of the course, Left: Students were doing comparison tests in Material Analysis Laboratory; Right: One testing sample of the granular proportion comparison test with high quality, 13/06/2012

索实践。从各组的夯土过程及其总结和交流中，体现出学生们在不断的施工挫折中被激发的求知欲，以及锻炼出的解决问题的能力。这都为后续的教学铺平了道路。

关于金工实验室的夯土墙建造，在接下来的课程中，已经掌握了一定夯土技术的学生将能够在这项工作中发挥更大的作用，在实践中达到学习目的。

依托于可持续建造实验室的建立和发展，夯土乃至生土建造课程必将成为我系建造课程体系中越来越重要的教学环节。已有的三次课程也积累了一定的教学经验，有助于日后该课程的发展成熟。当然，作为一门建造课程，在课程本身日益发展完善的同时，还需要考虑如何与其他课程的衔接和结合，如其他的建造课程、专业设计课程、民居考察课程和专业理论课程等，让学生对生土建筑的学习不停留在本课程上，而是能够继续深入并学以致用，为将来的实际应用打下坚实的基础，从而才有更多的可能。



工人在金工实验室工地上搭设脚手架，架设夯土模板，铺设防雨措施

Workers prepared the scaffold, rammed earth formwork, and rainproof measures, 13/06/2012

lectures, every student could truly and systematically participate the testing and construction in the condition of limited time and resources and join in the real construction site to complete the work. It is only when the students understand earth architecture and rammed earth construction completely that it is possible to reflect the true value of the course in their future professional study and working.

The course hasn't finished by the time the thesis is completed. But from the just finished experimental wall 1— initial experiment on rammed earth construction— the supposed result has been perfectly achieved. The students have explored and practiced the traditional rammed earth technology during the past seven days. From the ramming process of every team and in the summary and communication class, the students have been inspired greatly by failures they had experienced during the construction process and they have got the ability of problem solving, too. These will be helpful for the later teaching.

As for the construction for the rammed earth walls of the metalworking lab, the students who have already obtained certain ramming skills will surely play a greater role in the following course and achieve their learning purpose in practice.

Based on the establishment and development of SCL, rammed earth or even earth construction courses will definitely become the increasingly important element in the construction curriculum system. Some experience have been gained from the above three courses that will be helpful for the future development of such courses. Of course, as a construction course, it is necessary to consider how to connect it with the other courses such as other types of construction courses, design courses, courses of folk houses survey and theory lectures when it is improving itself so that the learning of earth architecture will not be restricted in this kind of courses but rather the students are capable of further learning, apply the knowledge and skills in practices and gain more possibilities for their future development.



## 4 中国生土建筑现状调查

从2009年筹建实验室至今,除了课程教学,我还陆续参与了多项生土工作,如生土民居考察、山西和甘肃的生土工作营和中国美院水岸山居夯土工程等。在此过程中,接触了包括居民、工匠、建筑师、专家学者、投资者和政府官员在内的来自不同领域,却因生土建筑而走到一起的人士,多方听取了各界人士对于中国生土建筑现状和未来的看法,这对于我们正在从事的生土建筑工作起到了一定的提示作用。

### 4.1 生土民居考察

2010年3月和11月,作为民居考察课程的带课教师,我先后带领学生考察了浙江省郭洞村和福建省永定县的土楼群。在郭洞村的考察过程中,学生们对当地居民进行了问卷调查,以了解夯土民居的使用现状。调查显示大部分居民认同土房子冬暖夏凉的舒适性,但由于土房子大多年久失修且缺乏现代设施而被现代生活舍弃,而更让他们介意的是土房子代表着贫穷。因为不难发现,即使在过去,裸露着生土表面的土房子也是穷人住的房子,而有钱人则会选择使用其他材料进行面层处理。现实是,一旦有了钱,人们会新建水泥红砖房,而不是维修土房子。缺乏生土建造和修复技术是一方面,观念上的“显富”心理则是更深层的原因。

事实上,这种现象普遍存在,即使贵为联合国文化遗产的土楼,周边新建的简陋粗糙的水泥红砖房也比比皆是,在申遗过程中经历了大量地拆除整顿。毫无疑问,申遗成功给福建土楼带来了机遇,让更多的土楼得以保护和保留,由此也促进了旅游业的发展,给当地带来了商机。旅游开发往往是一把双刃剑,带来经济利益的同时,难免因快速发展的需要而牺牲了真正意义上文化和传统的延续。随着人口的减少和外迁,土楼原有的家族聚居的兴旺景象,已被游人穿



初溪土楼群, 龙岩市永定县, 福建  
Chuxi Tulou group, Yongding, Longyan, Fujian, 11/2010

## 4 Investigations on the current condition of earth architecture in China

From the preparation of the lab in 2009 till now, besides teaching, I have also participated several programs on earth, such as field survey of earth folk houses, workshops in Shanxi and Gansu provinces and the project of “Tiles Hill” in CAA, etc. In this process, I have contacted with residents, craftsmen, architects, experts and scholars, investors and government officials of diverse areas who gathered together because of earth architecture. I have exchanged views on earth architecture in nowadays China and for the future with them, which has inspired us for our future work on earth architecture we are dedicating with. From the survey, we can expect the optimistic prospect of the application of earth on architecture from perspectives of the future architects. But for now, we should be aware of the reality China faces at. Reflection on the problems and experience gained from the establishment of SCL and the rammed earth teaching, it is not difficult to conclude that the problems are not the ones of a school or a course but rather the problems of the earth architecture faces in China.

### 4.1 Survey of the earth folk houses

In March and November 2010, as teacher of the folk houses survey courses, I took the team of students to Guodong village of Zhejiang province and Tulou in Yongding county of Fujian province to do field survey. In Guodong, the students made questionnaire survey on the local residents to acknowledge the using condition of the rammed earth folk houses. According to the interviews of the residents, it shows that most of them agree that the earth houses are more comfortable inside of which it is warm in winter and cool in summer. But they were abandoned by the modern life because of bad repair and lack of modern facilities. The residents also believe that earth houses represent poverty. It is clear that even in the past, the houses with the exposure of earth on the surface were for the poor. The rich chose to live in the houses with the surface covered with other materials. The reality is, people will build new houses with cement and cooked bricks as soon as they have money instead of repairing the old earth houses. On the one hand, it is because of lack of earth construction and repairing technologies and on the other hand for deeper reason is because people want to show their “wealth”.



郭洞村，金华市武义县，浙江  
Guodong, Wuyi, Jinhua, Zhejiang, 03/2010 (photography: He Jiangang)



梭的热闹景象所替代。如今,保存较好的土楼有的虽仍有部分原住民居住,但另有两种主要用途:旅游参观和旅馆住宿。

客观地说,旅游开发对当地的发展是必需的,不应以静置的眼光看待土楼功能的商业化转变。当今社会,在土楼丧失了它最初的防御和聚居的作用后,作为旅游者参观与居住体验的对象,不失为一种生存和发展的方式。只是,这种旅游开发应具有针对性和规划性。现实是,进入遗产名录的土楼被“小心翼翼”地保护着,几乎丧失了生活的气息;而仍在“生活”的土楼却因无力进行适当的维护,逐渐失去了真实生活中土楼的传统积淀和文化底蕴。

值得一提的是,去年10月,在厦门大学举行了可持续发展的结构暨夯土材料与结构国际研讨会,旨在揭示土楼的科学与工程价值及探讨其对现代可持续发展建筑的启示,并确定今后土楼的科学研究方向与内容。一直以来,对土楼的研究主要着眼于土楼的历史沿革与空间格局等,对其夯筑技术的研究则停留在对传统技术的记录与总结。因此研讨会令人对土楼夯土的科学研究与发展有了更多的期待。但据作为 CRA Terre 代表的 Marc Auzet 会后带回的消息,却让人失望。关于材料,与会的国际专家谈的是如何利用水泥加强夯土强度;关于发展,包括中国、美国、加拿大、英国、日本和澳大利亚的国际合作网络商讨的土楼合作研究课题,却更像是一次更大的商业开发项目。

我国的生土民居资源丰富,但人们对其历史文化意义缺乏认识,更谈不上保护意识。虽然由于旅游观光的经济价值促使人们开始认识到生土民居的意义,但是难以处理好保护与开发利用之间的关系。我们有时不得不无奈地面对“开发性”破坏,除了观念上的忽视,也因为我们



位于郭洞村西南方向的小山村山下鲍, 金华市武义县, 浙江  
Shanxiabao, a small mountain village to the southwest of Guodong, Wuyi, Jinhua, Zhejiang, 03/2010

In fact, the phenomenon is common. Even as the UNESCO culture heritage, Fujian Tulou were once surrounded by crude houses built with cement and cooked bricks, which had been dismantled largely while Tulou was applying for the UNESCO culture heritage. The success of the application has unquestionably brought opportunities, enabled the preservation and protection of more earth buildings and stimulated the development of tourism that would bring more commercial opportunities. But a coin has two sides. Besides economic profits, the fast speed of tourism development often has to sacrifice the continuity of essential culture and tradition. With the reduction and move-away of population, the prosperous family living in Tulou is replaced by tourists coming and going through. Now, the relatively good preserved Tulou houses though are still accommodating the original residents, their two other main purposes are for tourism and hotel accommodation.

Objectively, the tourism is necessary for the local development. This commercial transformation of the functions of Tulou shouldn't been seen statistically. After its functions of defense and gathering habitation have lost nowadays, as a way of existence and development, tourism and tourist accommodation are not a bad option. But such tourism development should be well purposed and planned. As a matter of fact, the earth houses listed in the heritage are being so protected that almost losing their daily life atmosphere; while the earth houses in which people are living are losing their tradition and culture accumulation of daily life because of disability to be reserved correctly.

It is worth mentioning that last October there was an International Workshop on Rammed Earth Materials and Sustainable Structures & Hakka Tulou Forum 2011: Structures of Sustainability in Xiamen University. Its aim was to reveal the scientific and engineering value of Tulou and explore its enlightenment to the modern sustainable architecture, making it clear the future scientific research direction and content of Tulou. Yet, the researches on Tulou have been focused mainly on its historic evolvement and spatial pattern; researches on rammed earth technology have been restricted in traditional technical records and summary. Therefore, the discussions on the conference were supposed to promote expectation of the scientific researches and development on Tulou. However,



左：承启楼底部的商业街；右：一栋普通的土楼内部，经主人自行改造修整，龙岩市永定县，福建

Left: Merchandise street inside Chengqi Tulou; Right: Interior of a common Tulou, which had been repaired and reconstructed by the owner, Yongding, Longyan, Fujian, 11/2010



缺乏正确的开发理念和技术支持。所以，当我们的考察队伍来到郭洞村附近的山下鲍时，会为其未被开发而保留的原汁原味而震撼，而庆幸。可是，这样一个贫穷、濒临荒废的传统山村，它的未来又在哪里呢？

## 4.2 夯土工作营考察

去年8月，在甘肃省会宁县马岔村的“土筑”建造试验工作营，目的是进行现代夯土农宅的建造试验，由大学生志愿者和当地村民共同建造。整个过程其实也是面向当地居民的一场夯土建造宣传教育和现场培训。村民们开始时对使用新方法（材料配比、现代工具）夯土持怀疑甚至排斥的态度。当现场以新老方法同时对比施工时，当地传统方式的椽式模板在建造速度上有优势，但未经配比的土墙质量则明显不佳。通过现身说法，村民们能够接受改进材料的配比，但对于使用现代模板和气动夯锤则仍然觉得不是必须。

的确，在这样偏远贫穷的地区，用土造房仍是当地重要的建造方式，因而传统的夯土技术沿用至今。村民们自建土房子，图的无非是便宜，就地取材、工具现成，再让亲戚朋友帮帮忙，连人工费都省了。他们的确不具备为夯土配备一系列额外工具和设备的条件。因此，要让农民提高自建农宅的夯土建造质量，适合于首先推广的，应是土料配比的改进和构造措施的合理化，工具设备的现代化则应根据现实情况采用。事实上，基于早前夯土农宅实践，同样是此工作营的发起者香港无止桥慈善基金，和住房和城乡建设部村镇建设司共同编写了《抗震夯土农宅建造图册》，以图文并茂的方式，浅显易懂地介绍了抗震地区自建夯土农宅的施工流程和质量控制要求。但遗憾的是，这样一本面向农民和工匠的实用型图册，至今并未在农村中流传，真正发挥它的作用。

2010年10月，在山西省平遥县梁村的西宁堡堡墙修复工程，同样是作为传统夯土城墙保护的试验性工程，由当地村民使用传统的方式进行，一来展示传统的夯筑技术，二来向当地人宣传传统建筑的价值和维护可行性。当地的夯土原使用纯生土，但易受侵蚀。后在同济大学教授的建议下，在夯土墙修复过程中添加石灰以改善防水性和强度。除了生土材料，其他基本沿用了当地传统的夯土方式，如椽式模板、石杵和铁砢（一种较大的夯锤，石制或铁制，需四人同时使用）。由于堡墙较厚，因此在工作面允许的情况下，还使用了路面夯实机。对于堡墙的



”土筑“工作营建造现场，左：完工的夯土墙；右：工作营的现场准备工作，马岔村，白银市，甘肃

Building site of "earth construction" workshop, Left: completed rammed earth walls (photography: Zhou Gongzhao); Right: Preparation of the workshop on the site, Macha, Baiyin, Gansu, 08/2011

according to Marc Auzet, who attended the conference as representative from CRATerre, it was a disappointing conference. As for materials, the international experts talked about how to reinforce the strength of rammed earth with cement; as for development, including the collaborative research program of Tulou proposed by the international network between China, USA, Canada, Britain, Japan and Australia, was more like a larger commercial development project.

China has abundant resource of earth folk houses, but people have not realized the historical and cultural significance, not to mention the intention of protection. Though the economic value of tourism has impelled people to realize the meaning of earth folk houses, it is difficult to deal with the relationship between protection and development & use. Sometimes, we have to face the “developmental” destruction. Additional to the conceptual ignorance, we also lack of correct development concept and technical support. That’s why when our team arrived in Shanxiabao village near Guodong, we were deeply impressed by the undeveloped condition with complete preservation of the original status and were relived. But, for such a poor, almost abandoned traditional village, where is its future?

## 4.2 Survey of rammed earth workshop

In August last year, there was an “Earth Construction” experimental workshop in Macha village, Huining county of Gansu province. The purpose was to do construction experiment for the modern rammed earth country houses. The volunteers from universities built with the local villagers together. The whole process was in fact a promotion and training for the local residents about rammed earth construction. At the beginning, the villagers were doubt on the new methods (such as material proportion, modern tools) of rammed earth or even refused them. When constructed on the site with both new and old methods, the local traditional rafter formwork took superior on the construction speed, but the earth wall with no proportion had lower quality. From this process, the villagers could accept the improved material proportion, but they didn’t feel it necessary to use the modern formwork and pneumatic rammer.

Indeed, in such a remote and poor area, earth is still an important way to build houses there. So the traditional technology has been used till now. The villagers build earth houses by themselves for the sake of low cost. Local materials, ready tools and help from relatives and friends—even with no cost for the labor. They really don’t have the condition for extra tools and facilities for ramming. Therefore, in order to improve the quality of the rammed earth village houses, the improved proportional earth material and optimized structure measure might be the first option to promote. And the modernization of tools and facilities should be applied accordingly. In fact, based on the rammed earth village house project, Wu Zhi Qiao (Bridge to China) Charitable Foundation, as the initiator of this workshop has compiled together with Department of Village Construction, Ministry of Housing and Urban-Rural Development of China a book *Anti-Seismic Rammed Earth Village House DIY Construction Manual*. The book introduces the construction process of self-built rammed earth village houses and the quality controlling requirement with texts and illustrations, which is easy to understand. But unfortunately, such a practical illustration book for farmers and craftsmen has not yet been widely spread in villages and played its role there.

In October 2010, the renovation project of the wall of Xi’ningbao fortress of Liang village, Pingyao

修复，当地人的方法比较激进，这与来自法国巴黎夏佑学院师生希望采取的保守方法在观念上存有差异，因此在施工过程中也曾引起激烈的争论。

此次工作营作为同济大学和巴黎夏佑学院关于历史建筑保护的联合课程，事实上不仅仅是一次试验工程，对当地政府而言，更是作为西宁堡旅游开发基础建设的开始。作为一项需要产生经济效益的修复工程，当地政府的目的在于高效高质的完工，并不太在意堡墙的历史价值。因为在当地人看来，这次的修复工程不过是堡墙在建成一百多年来历经数次修补后的又一次大规模维修而已。对此，他们有自己的工作方法和经验。而来自法国和美国的专家学者则将堡墙作为学术研究和实践的对象，更加关注堡墙历史价值的保留和修复工程的示范意义。两者的价值取向不同，处理问题的方式也就难免存在分歧。

从这两次在农村实地的夯土工作营来看，当地的夯土技术仍有一定的群众基础。虽然这一传统技术的保留和传承并非源于他们对夯土的珍视，而是在经济条件制约下必须掌握的生活技能，但这为我们进行生土民居的保护和新建提供了良好的基础。必须注意到的是，工作营试验性工程的开展可以是理想化的，以达到宣传教育的效果。但考虑到实际操作性，还需要继续探索更容易让当地的工匠和使用者可以接受的方法。有时，这意味着作为专业人士应该做出一定的“妥协”，以便让当代的生土建造在农村里真正切实可行。

### 4.3 夯土工程考察

从去年9月即开始了王澍教授水岸山居夯土工程的试验，自今年4月起正式施工。由于取自施工现场的土用于夯筑，不但需要砂石配比，还得先经粉碎，备土的加工程序较多，成本也高。因此在试验阶段，不但工人们难以严格按照既定的施工程序，连施工负责人也试图简化工序、偷工减料。此外，还因为许多工人曾经在农村造过夯土房子，经常凭借以往的经验想当然地进



西宁堡堡墙修复工程现场，左：被铲倒的危墙；中：拆除顶部不稳定墙体；右：修复后的堡墙，梁村，平遥县，山西

Building site of the renovation of the wall of Xi'ningbao, Left: Dangerous part of the wall was moved; Middle: Top of the wall was moved to avoid falling down; Right: Repaired wall (photography: Sun Xiangwu), Liangcun, Pingyao, Shanxi, 10/2010



County, Shangxi province was an experimental project of preservation of the fortress walls of traditional rammed earth. The local villagers used traditional methods to do it. On the one hand was to show the traditional rammed earth technology and on the other hand was to promote the value of traditional buildings and the possibilities of protection. The earth for local ramming was pure earth, but was easy to be eroded. Then with the proposal of a professor from Tongji University, lime was added in the repair process in order to improve the waterproof and intensity. Besides earth, other local traditional ways of ramming earth was used, such as rafter formwork, stone rammer and “wo” (a kind of bigger rammer made of stone or iron and need to be operated by four workers). Since the wall was thick, road compactor was used when the working situation allowed. For the repair of the wall, the local people tended to use some radical methods, which was in conflict with the reserved methods of the teachers and students from Chaillot school of Paris. So there had been severe debate during the construction process.

As a collaborative course between Tongji University and Chaillot school of Paris on historic preservation, the workshop was not only an experimental project but an initial point for the infrastructure of the tourism development in Xi’ningbao Fortress to the local government. As a renovation project that required for economic efficiency, the purpose of the local government was to finish it effectively with high quality. The historic value of the fortress was neglected, because for the local people, the renovation project was just another large scale repairing after the wall was built over a hundred years. Therefore, they had their own working methods and experience. While the experts and scholars from France and US took the fortress wall as an object for academic researches and practice. They paid more attention to the historic value of preserving the wall and the demonstrative significance of the renovation project. The two completely different value orientations led to different ways to deal with the problems.

From these two workshops in the countryside, the local rammed earth technology still has its mass basis. Though the preservation and inherit of the traditional technology is not derived from their



工人们在修复工程中使用的夯筑工具，左：石杵；中：铁碾；右：路面压实机，梁村，平遥县，山西

Ramming tools used by the local workers in the renovation project, Left: Stone rammer; Middle: Iron rammer iron used by four people; Right: Road compactor, Liangcun, Pingyao, Shanxi, 10/2010



行操作。这样简化工序的施工最终导致试验时夯土质量不高。

为保证施工质量，校方对夯土工程的承包再次进行了调整。幸运的是，新的施工负责人倪工并不因循守旧，而且善于沟通。虽然在承接工程之初，他对施工的各个环节仍心有疑虑，总试图寻找替代方式来简化工序、提高效率、节约成本，比如他曾自行制造了过筛机试图用以代替粉碎机，事后证明并不可行。经过多方尝试，并经过我实验室人员的多方解释，和在实验室试验的眼见为实后，他终于完全信服我实验室建议的现代夯土技术，并以此严格要求工人的施工操作。令人欣慰的是，由于施工负责人理解并信任现代夯土技术，并负起责任，施工质量就比较容易得到保证。但在此过程中，校方认为夯土表面不适用于居住房间的内墙面，修改了夯土墙方案，即在墙体内表面砌砖 240mm 厚，夯土部分仅剩 360mm 厚。对于此举将导致的安全隐患，实验室提出了拆除砖墙、恢复原设计，并以面层处理改善夯土墙面走砂的建议。

从夯土试验到施工遇到了一系列问题，然而王澍教授始终对夯土建造保持高度的信心。关于夯土在中国的现状和发展，王澍教授谈了两个方：一是观念，二是技术。从他经历的三次夯土经验来看，人们看待夯土从一开始对夯土雕塑的不接受，到宁波公园茶室能够接受夯土用作茶室墙体，再到此次水岸山居工程进一步接受夯土墙用在旅馆这种带居住性质的建筑中，但仍然怀疑其直接作为内墙面的可行性。可以看到，人们的观念已在逐渐改变，尽管要真正完全接受还有待时日。但王澍教授相信，只要技术上能够日趋完善，随着生土建筑在当代应用的步



“水岸山居”夯土现场，底部夯好的土墙被遮盖以防雨

Building site of "Tiles Hills" project, the completed rammed earth wall on the bottom was covered to protect against rain, 05/2012

treasuring of it, but rather a kind of living skill under the economic restriction. Nevertheless, this has provided us good foundation for the work of preservation and newly construction of earth folk houses. It has been noticed that the experimental projects in workshops might be idealistic in order to achieve the aim of promotion and education. But taking into consideration the practical operation, we need to explore easier method that the craftsmen and users are able to accept. Sometimes, this means that the professional practitioners has to compromise in order to make the contemporary earth construction feasible in the villages.

### 4.3 Survey of rammed earth projects

The experiment for the “Tiles Hill” project designed by Prof. Wang Shu started from September last year and the construction started from April this year. Since the earth was excavated from the construction site, it required not only to be mixed with sand and gravel, but also to be smashed first. There were many procedures of earth preparation and the cost was high. Therefore, in the experiment phase, the workers didn’t follow the planned construction procedure strictly. The person in charge of the construction also tried to simplified the procedures and reduce the material. What’s more, since many workers had built rammed earth houses in the countryside, they often operated according to their former experience at will. All of these finally led to the low quality of the rammed earth in the experiment.

In order to ensure the construction quality, the client decided to adjust the commission of the rammed earth part of the project. Fortunately, the new person in charge of the construction, Engineer Ni, is not a person restricted in conventions and easy to communicate with. Nevertheless, he was also a sort of suspicious with the procedures of the construction at the beginning; he always tried to find options to simplify in order to be more efficient and cut the cost. For example, he had produced a sieving machine to replace the smashing machine, which turned to be infeasible. Finally, he believed completely in the modern rammed earth technology proposed by the lab after many attempts, several times of explanations by the staff of the lab and witnessed the tests himself. As a result, he strictly asked the workers to follow the construction procedures. To our relief, the construction quality will be ensured given that the person in charge understands and believes in modern rammed earth technology and takes the responsibility. But during the process, the client didn’t think that the rammed earth surface could be used as the interior surface of the rooms, the plan for the rammed earth walls were revised. The new plan was that the interior part of the walls would be 240mm thick cooked bricks and the rammed earth part would be only 360 mm thick. Considering the danger that would be caused by this new plan, the lab proposed to demolish the brick walls and returned to the original design; and the wall surface could be treated to avoid grains falling.



距离施工现场几百米外的备土场，中国美术学院校园

Site of preparation of the earth for the "Tiles Hills" project, which is hundreds of meters away from the building site, CAA campus, 05/2012



步推进，人们的观念也一定会随之改变。尽管目前仍有诸多问题，但他一再强调，将坚定地继续夯土建造，并期待能与 CRATerre 有更加深入的合作。

凭借目前在建筑领域的声望地位，王澍教授完全有更多的机会去实现他在生土建筑上的想法。目前在中国，除了偏远农村由于贫穷不得已还建造土房子外，生土建筑的新建案例很少。众所周知的，如穆钧教授在甘肃的毛寺生态实验小学，张永和教授在长城脚下公社的“二分宅”，



上：五散房茶室，建筑师：王澍，宁波，浙江；下：毛寺生态实验小学，建筑师：吴恩融、穆钧，毛寺，甘肃

Top: Tea House of the Five Scattered Houses, architect: Wang Shu, Ningbo, Zhejiang

Bottom: Maosi Ecological Demonstration Primary School, architects: Edward Ng Yan-yung, Mu Jun, Maosi, Gansu (photography: Mu Jun)



From the rammed earth experiment to the construction on site, a series of problems encountered, Prof. Wang Shu kept confident with the rammed earth construction. He expressed his opinions about the current status and development of rammed earth in China from two perspectives, concept and technology. From his three times experience of projects with rammed earth, people's attitude toward rammed earth has changed from non-acceptance from the first rammed earth sculpture, and then acceptance with the walls for the Tea House project in the Ningbo park, to finally more acceptance with the rammed earth walls for buildings like a hotel in the "Tiles Hill" project but still being suspicious of the feasibility of rammed earth wall as the interior wall. It is evitable that people's concept has increasingly changed, though they need more time to truly and completely accept this. Prof. Wang Shu believes that as long as the technology can be improved gradually, with the proceeding of earth buildings in contemporary society, people's concept will definitely change. Though there are still many problems, but he insists that he would continue to try more rammed earth construction and is looking forward to deeper collaboration with CRATerre.

With his reputation in the architecture area by now, Prof. Wang Shu has absolutely more opportunities to realize his ideas about earth architecture. So far in China, earth houses are only built in the remote countryside for the reason of poverty. New buildings of such kind are very few, the well-known projects, such as Maosi Ecological Demonstration Primary School, Gansu province, designed by Prof. Mu Jun, Split House located in the Commune by the Great Wall designed by Prof. Zhang Yonghe, and in the folk, Anji Ecological Houses designed by environmentalist Ren Weizhong in Anji, Zhejiang province.



任卫中的安吉生态屋，左：1号房室内；右上：3号房；右下：4号房和2号房，湖州市安吉县，浙江  
Anji Ecological Houses designed and constructed by Ren Weizhong, Left: Interior of House 1; Top right: House 3; Bottom right: House 4 and House 2, Anji, Huzhou, Zhejiang, 04/2008



在民间，则有环保人士任卫中的安吉生态屋。

2008 年，在毛寺生态实验小学获得首届中国建筑传媒奖 (China Architecture Media Award) 最佳建筑奖时，安吉生态屋项目也获得了同一奖项的提名。安吉生态屋的建造作为任卫中的个人行为，其目的正是为了在农村推广包括夯土在内的生态材料的使用，环保的同时减轻农民建房负担，并保持乡土特色。作为非建筑专业人士，他个人出资并设计建造了五幢实验性生态住宅，对农宅建造中土木材料构造以及当下民居功能空间进行积极尝试与探索。同时，他为生态住宅的推广制订了明确的发展计划。然而个人的力量终究是有限的，尤其在 2010 年国家施行“建材下乡”的政策后，看似给农民使用钢筋混凝土造房给予了实惠，却让农宅更加远离了乡土建造。可以想见，这一政策给安吉生态屋项目在推广上带来的不利影响。

由此可见，尽管我国生土民居历史悠久，资源广阔，但当代生土建筑凤毛麟角。抛开这些名声在外的实施个例，一般的项目投资者或者政府官员是否接受并推进生土建筑应用于中国城市或乡村中的新建或改建项目，将大大影响生土建筑在中国的发展。



安吉生态屋 3 号房夯土建造现场，湖州市安吉县，浙江

Building site of the rammed earth walls of House 3 of Anji Ecological Houses, Anji, Huzhou, Zhejiang (photography: Ren Weizhong)

In 2008, when the Maosi ecological primary school was awarded the best architectural prize of China Architecture Media Award, the Anji ecological houses project was nominee of the same prize. The construction of the ecological houses project in Anji was Ren Weizhong's personal behavior. The purpose was to promote the application of ecological materials including rammed earth in the villages, Reduce the farmer's burden of building and keep the features of countryside. As non-architectural professional person, he invested personally five experimental ecological houses and did active attempts and explorations on the wood and earth materials and structure of the village house construction as well as the functional space of the current folk houses. At the same time, he made a specific developing plan for the promotion of ecological houses. However, personal power is too limited, especially with the policy of "construction materials for the countryside" in 2010, it seemed that the farmers have gained profit from the usage of concrete and steel for their houses, but the country houses have been driven further away from the local construction. It could be anticipated that this policy will bring negative influence to the promotion of Anji ecological houses project.

Therefore, though the earth folk houses in China have a long history and the resources are wide spreading, the modern earth buildings are seldom seen. With exception of these renowned projects, whether the common developers or government officials could accept and promote the application of earth architecture in the new projects or renovation projects in the cities or villages will greatly influence the development of earth architecture in China.



安吉生态屋的建造及其发展计划，上：生土同时应用于屋顶和木骨泥墙；左下：生态屋内举办乡村讲习所，向村民推广生态建造技术；右下：生态屋的推广发展计划

Construction and development plan of Anji Ecological Houses, Top: Earth also used for the roof and wooden frame wall; Bottom left: Village assembly was held in Ecological House to introduce the ecological construction to the villagers; Bottom right: Development and promotion plan of Ecological Houses made by Ren Weizhong (images and drawings provided by Ren Weizhong)



## 5 结语

课程教学，让我们看到学生们积极的学习热情，体现出这些未来建筑师对生土建筑应用的乐观前景。但此刻，我们更应该清楚地看到生土建筑正在中国面临的现实。反观文中所述的一系列生土工作中经历的问题和取得的经验教训，不难发现这不是一个学院或某一工程面临的问题，而是整个中国生土建筑领域所一致面临的问题。

### 5.1 中国当代生土建筑发展方向的探讨

事实上，近些年我国在各行各业大力提倡可持续发展策略，同时鼓励发展文化产业，重视传统文化的保护和发展。可见，生土材料的可持续性和我国悠久的生土建造传统都将是生土建筑回归的最好理由。而目前最缺乏的，是信息，是技术。

在国外，现代的、科学的生土建筑研究已“悄悄”进行了近四十年，成功的工程案例也已遍布各大洲。而我国的建筑业对此知之甚少，更不用提业外人士或普通民众了。我们不知道，原来用土也可以把房子造得很坚固、很舒适、很现代，老的土房子也可以被修复和保护得“光鲜靓丽”，并不总是农村里“土得掉渣”，一副破败的模样，更不是只有穷人才住的房子。都说人们对生土建筑存有偏见，其实那是无可厚非的，由于信息的缺乏，确实没见过符合“现代审美观念”的生土建筑。

再说技术。传统的生土民居尽管多已破败，但能保留到现在，说明当时的技术还是比较讲究的。而要保证土墙质量，施工更耗时耗力。看看我国遍布的传统生土民居，但凡有条件的，大多在土墙外表抹了灰，或覆了面砖，一来保护，二来平整美观。这些措施，恰是因为对生土材料缺点的充分了解。他们是对的，待光华褪去，缺乏维护的土房子现大都成了危房。所以，当红砖、水泥、混凝土以坚固耐久、施工便捷的形象出现，自然就成了人们的首选。即使是现在，许多农村里中年以上的人都见过，甚至亲手造过土房子，主要是夯土，他们叫“打土墙”。时代不同了，打土墙更是一种“穷人家”才用的方式。这在农村里被视作一种非常朴素直接的建造技术，不是啥高难度的技术活，更失去了传统建造时的那一份讲究和细致，只是没钱盖房的一种廉价、低技的解决方式。问题是，我们不知道，其实生土的建造已被研究发展成为一门



CRATerre 主办的第十届国际生土节，左：生土建筑及建造展览；右：生土建造工作坊，Les Grands Ateliers，伊泽尔省，法国  
HABITER LA TERRE—10th FESTIVAL GRAINS D'ISERE hosted by CRAterre, Left: Exhibition of earth architecture and construction, Right: Earth construction workshop, Les Grands Ateliers, Isere, France, 05/2011

## 5 Conclusion

From the teaching course, we can see the active learning enthusiasm of students, which reflects the optimistic prospect of the application of earth on architecture from perspectives of these future architects. But for now, we should be aware of the reality that China faces at. From the problems and experiences from the work of earth mentioned above, it is not difficult to conclude that they are not problems a school or a project faces, but rather the problems of the earth architecture faces in China.

### 5.1 Development direction of contemporary earth architecture in China

In fact, all areas of China are promoting the sustainable development strategy in recent years and encourage the development of cultural industry; the preservation and development of traditional culture is attached great importance. Therefore, the sustainability of earth material and the long history of earth construction will be the best reason for the returning of earth architecture. Now, the worst needed is information and technology.

In the foreign countries, modern and scientific earth architecture researches have been undergoing for almost forty years. Successful projects spread all over the continents. But the architectural industry of China doesn't know about this, not to mention people outside of the field or the common people. We didn't know that buildings could be solid, comfortable, modern by being constructed with earth, that the old earth houses could be renovated and protected so well that they don't always present those "extremely outdated" and terribly ruined appearance; what's more, they are not just for the poor. It is said that people are prejudice to the earth buildings; that is true. Since there is no enough information, most people have never seen earth buildings that match the modern aesthetics.

Then let's talk about technology. Most of the traditional earth folk houses are tumbledown but can still exist until now, which means the technology at that time was particular. In order to ensure the quality of the earth wall, it cost much time and work in construction. Observing the traditional earth houses around China, as long as it was possible, the exterior of house would be covered with lime mortar or gray bricks in order to protect the walls as well as for aesthetic reason. Those measures were exactly based on the acknowledgement of the defect of earth material. They were right. When the glory faded, the earth houses without preservation had become dangerous ones. So when cooked bricks, cement, concrete emerged as stable, durable and easy construction material, they became the first choice of people. Even now, middle aged villagers have seen or even built earth houses (mainly rammed earth, which they call it "hit earth wall") themselves. In a different age, the method "hit earth wall" is only used by "the poor". It is considered to be a very simple and direct construction skill instead of some high tech in the countryside. What's more, it has lost the particular and delicate part in the traditional construction; it is rather a cheap, low tech solution to build a house for those who have no money. The problem is we have no idea that the earth construction has been developed into a professional applied engineering technology, obtaining complete systematic theory on material property and construction technology. Now, earth construction has its theoretical basis; the construction quality is controllable and the building quality is ensured. In a word, the technology is no longer a problem.

It is imaginable that with seeing the modern and beautiful earth buildings as well as the feasible and reliable technology, people will change their inherit ideas toward earth architecture. Taking



专业的应用工程技术，具备了完整的材料性能和建造技术的系统理论。生土建造从此有据可依，施工质量得以控制，建筑质量可以保证。一句话，技术不再是问题。

可以想见的是，当见识了现代光鲜的生土建筑，又有可靠可行的技术可用，人们对生土建筑的固有观念一定会发生转变。再加上前文所及的生土所具备的可持续性，和生土建造所承载的文化传统，使得在中国保护和发展生土建造不仅具有迫切性，还具有了可能性。此时，作为此信息和技术的掌握者，首先要做的，应该是宣传，是用实例和实力进行的宣传，转变观念，推广技术。

幸运的是，就在去年年底我遇到了这样的一次机会，来证明这种做法是可行的，就是在云南大理国际文化城项目上。从该项目策划伊始，可持续建造和地域文化被定位为项目总体规划的核心价值。难得的在于，这个项目几乎具备了使用生土的各种要素，场地周边大理传统生土民居的地域特征、项目的文化和旅游性质、高密度小尺度的建筑类型。经过我与投资方的多次沟通，他们非常认同以生土建筑作为该项目的切入点，在取得环境效益的同时，还取得了良好的社会效益，也有助于产品的推介，是个一举多得的好想法。他们已能够在观念上认同、技术上信任，唯一担心的就是生土的造价和建造工期等操作层面的问题。这是完全可以理解的，项目投资者不是公益机构，必须考虑经济成本和时间效益。而在政府层面，当地的政府官员希望以此文化项目作为生土建造的示范工程，进而在辖区内推广应用，这将是一件利国利民的实事。

通过此项目的进程，可以看到凭借眼见为实的成功案例让人们去接受新建生土建筑已不是难事。如果说这是政府官员和项目投资者所具有的远见，那么对于传统生土民居的保护，作为实际使用者的老百姓是否也能够接受呢？同样是在大理，大成村历史文化名村的保护开发项目



大成村生土民居，大理市挖色镇，云南  
Earth folk houses in Dacheng village, Wase town, Dali, Yunnan, 03/2012

into consideration of the above mentioned sustainability of earth and the cultural tradition of earth construction, it is not only urgent but also possible for the protection and development of earth construction in China. At this time, as mastering with these information and technology, the first obligation is to promote with real examples and ability to change the concept and spread technology.

Fortunately, I had such an opportunity at the end of last year to prove this is feasible. It was a project of an international cultural city of Dali in Yunnan province. Sustainable construction and local culture was positioned as the core value of the general planning for the project. It was unusual that the project was almost qualified with all the elements for using earth—the local features of the traditional earth houses around the city of Dali, the cultural and tourism characteristics of the project, small scale of buildings with high density. I had communicated with the investors for many times and they agreed highly that earth buildings could be the initial point for the project, which would be environmentally beneficial and socially influential as well as efficiently promotive to the product. In a word, it would achieve multiple objectives at one time. The clients had accepted the ideas and believed in the technology. The only doubt was problems during operation such as the cost and time consuming for earth construction. It was reasonable. The investors of the project are not charity organizations. They had to consider the cost and time efficiency. While the local government and the officials hoped that this cultural project would be a model project for earth construction and could be further promoted in the whole area. This will be good for the country and the people.

From the latest progress of the project, it can be said that it is not difficult to persuade people to accept newly built earth buildings with real successful examples. If this is the government officials' and investors' foresight on earth buildings, is it acceptable for the users of common people to preserve the traditional earth houses? Also in Dali, in the preservation and development project of the historic and cultural village Dacheng in Dali, with our active promotion, we advised the local government to invite CRATerre to join the project to support technically in order to facilitate the effective protection and active renovation of the local earth folk houses resources instead of simply massive demolishment and construction to produce fake products of bad quality. The local government apparently showed



喜洲镇的生土民居，大理，云南  
Earth folk houses in Xizhou town, Dali, Yunnan, 03/2012



中，我们积极宣传，希望当地政府能够邀请 CRATerre 提供技术支持，促成当地生土民居资源有效的保护和积极的改造，而不是简单地大拆大建，制造粗劣的仿制品。当地镇政府对此显然是有意向的，但要付诸于实施，还有待各方的共同努力。

不难看出，在中国，生土建筑项目是具有发展前景的，无论是保护项目还是新建项目。但同时也应该看到，这条路充满艰辛。就以王澍教授“水岸山居”夯土工程为例，尽管他本人坚定地相信 CRATerre 提供的现代夯土技术，要求施工队在可持续建造实验室的技术指导下进行施工。但在实施过程中，频频遇到质疑声，不仅来自施工队，甚至来自项目的投资方，中国美术学院的校园基础建设管理处。质疑主要集中于两方面：一是夯土操作流程复杂，成本高；二是旅馆房间内夯土墙表面粗糙，需处理。这第一点，由于有试验墙体的实际对比效果摆在眼前，因此决定质量优先。而第二点，王澍教授也曾做出内部砌砖墙的妥协，但最终还是听取了实验室的建议，拆除已砌墙体，安全优先。在此项目的试验和施工阶段，一次次新的技术理念和老的传统观念的摩擦，都让人深感要真正推广一项新技术的难度，现实和理想的差距。但幸运的是，虽然过程磕磕碰碰，但最后是向好的方面发展。施工方和投资方也能够在夯土过程中积极总结经验，不断磨合，并发挥创造力，为实现如此大型、复杂的夯土墙安全高质的建造而努力。

如今此项目的夯土墙已建成一小部分，施工队伍也完成了现场夯土的初步探索。但不得不提的是，此夯土工程的成本大大超出了预算。这难免让人怀疑提倡生土应用的优势之一——廉价。但是，考虑到此项目的特殊性，而且作为首个尝试大型夯土墙体的工程，试验总要付出代价的。相信随着施工越来越常规化、正轨化，成本会逐渐下降。事实是，经过两个月的现场施工，据负责人倪工提供的数据，夯土造价已降至约 1800 元 /m<sup>3</sup>（钢筋混凝土约为 800-900 元 /m<sup>3</sup>）。

从以上一系列生土项目的策划或实施的事件中可以看出，当生土建造的技术不成问题，因技术质量的要求和人工费用的提高带来的生土建造成本的增加将成为其推广发展的制约。而究



大成村的古建，左：正在被拆毁的夯土墙；右：当地人用劣质的贴面仿木构修复文昌庙，大理，云南

Old architectures in Dacheng, Left: Rammed earth walls being dismantled; Right: Repaired wooden structure of Wenchang Temple by covering the inferior veneer overlay by the local villagers, Dali, Yunnan, 03/2012



interest in doing so. But it needs efforts from various aspects before it could be implemented.

It is not difficult to see that in China earth architectural project has its prospect of development, no matter in preservation projects or newly built projects. But we also have to see the way leading to the prospect is full of obstacles. Taking the example of Prof. Wang Shu's "Tiles Hill" rammed earth project, though he firmly believes the modern rammed earth technology provided by CRATerre and have told the construction corps that they had to follow the guidance of SCL on the technology, during the construction process, there often appeared all kinds of queries not only from the construction corps but also even from the investor of the project, the administrative office for the infrastructure, CAA. The queries were mainly focused on two aspects: one was the complicated operation process of rammed earth, which costs too much; the other was the rough surface of the interior walls of the hotel, which required to be dealt with. For the first point, since the result of the experimental walls for comparison was very clear, so it was privileged on quality. For the second point, Prof. Wang Shu had also compromised that the interior walls changed into brick walls, but finally he accepted the proposals of the lab to demolish the already laid brick walls for the sake of safety. In the experiment and construction phase of the project, conflicts of new technical ideas with old traditional ideas had brought people to see the difficulty of promoting a new technology and the distance between reality and ideal. But fortunately, though there were unexpected conditions during the process, but finally it was oriented to a good direction. The construction team and the investor are willing to sum up their experience during the ramming process, compromised each other, tried to be creative and made great efforts for the realization of such a huge and complicated rammed earth project with good quality.

So far, a small part of the rammed earth walls have been completed. The construction team has also finished preliminary exploration for the site ramming. But it has to be mentioned that the cost of the ramming project is far more than the budget. Inevitably people will doubt one of the advantages of the application of earth—low cost. But taking into account the specialty of the project and as the first attempt of large scale project with rammed earth walls, experiment has to pay. We believe that as the more regular and standard the construction is, the less the cost will. In fact, according to the data from Engineer Ni who is in charge, the cost of rammed earth has been reduced to about 1800 RMB/m<sup>3</sup> (the cost of reinforced concrete is 800-900 RMB/m<sup>3</sup>) after two months construction on site.

From the above plan or implementation of earth projects, it can be concluded that when the technology for earth construction is not longer a problem, the increasing of building cost caused by the requirement of technical quality and higher labor cost will be the restrictions for its popularization and development. The reason for this is because earth construction in China is still a project of minority. Compared with its development in countries like France, what we need to learn from them is to establish an industrial chain for the earth architecture, including companies for material processing, professional construction companies, education and training institutes for earth architecture, earth architecture associations and so on. They will run independently but support each other. With such an industrial chain, massive scale effect will be formed, and the earth construction will increasingly been involved into the modern industrial construction system; the cost will be reduced, and that will help to promote the sustainable development of earth architecture.

It has to admit that the formation of such an industrial chain will not be achieved in a sudden. It has to be based on the development needs and phases. As far as I know, in France, CRATerre was

其原因，生土建造在我国仍属零星工程，相比法国等国家的生土建筑发展，我们要学习的，就是在将来建立起一条生土建筑产业链，包括材料加工生产企业、专业建造公司，生土建筑教育及培训机构，生土建筑协会等，各自独立，又相互支撑。通过产业链，形成规模效应，将生土建造逐步纳入现代工业化建造体系，降低建造成本，有助于生土建筑的持续发展。

应该承认，这样一条产业链的形成不在一朝一夕，是基于发展的需要和阶段。据我所知，在法国，CRATerre 作为生土建筑研究和实践的先驱，成立于 1970 年代，而基于理论和实践研究的 DSA 课程教学也始于 1980 年代，2000 年开始举办一年一度的国际生土节，作为专业人士学术交流、专业课程教学、和大众普及教育与宣传的平台。也正因为 CRATerre 的专业教育，培养出一批批生土建筑的专业人士，其中有人则创办了专门加工生产和销售生土建造用材的 AKTERRE 公司，提供如夯筑成品用土、各种粘土等生土材料，和石、砂、稻草等各种添加材料。此外，还有一些专门生产生土成品构件的小公司，如挤塑生土砖、生土保温砖等。与此同时，随着当地生土农宅修复或新建项目建造需求的日益增大，出现了专门从事生土建造的建筑公司。如 CARACOL 就是法国一家有名的生土建造专业公司，其业务范围还拓展到生土建造培训，每年举办若干期面向公众的不同专题的培训课程或讲座。这些公司还共同成立了生土建筑协会 ASTERRE，定期举行会议，相互了解行业状况，交流工程技术，共促发展。

可以看到，历经近四十年的发展，法国的生土建筑产业初见规模，从工程方面的专业建造、专业厂家，到研究方面的专业实验室，再到教育方面上的专业学院，以及宣传方面的一系列国际展览、论坛和互动活动等等，已基本涵盖了目前生土建造的方方面面。必须指出的是，尽管如此，并不意味着生土建筑在法国已蓬勃发展，事实上生土建造在法国仍是小众事业，应该说距离生土应用的目标理想还有距离，需要技术上的进一步完善和推广。

毫无疑问，这些国外已有的研究和实践经验，为我国生土建筑的发展提供了借鉴，指明了方向。虽然在此基础上的发展可以缩短摸索的时间，但生土建筑毕竟是一个以应用实践为主的事业，因此仍需现实的条件下一步一个脚印前进。在我国，不用说生土建造的发展目标是工业化、产业化，就连目前的混凝土建造也还未达到国外的工业化程度。就以夯土技术为例，支模、拆模的效率，模板系统的坚固度等，大大影响夯土的成本和质量。而目前国外夯土借用的混凝



左：CARACOL 举办的生土培训课程中，学院在学习给老的夯土墙开窗和修复技术；右：CARACOL 生土建造公司的工作坊，格勒诺布尔  
Left: Students were learning to make a window hole in the old rammed earth wall and repair technique in the earth training course hosted by CARACOL;  
Right: Workshop of CARACOL, Grenoble, 03/2011

established in the 1970s as the forerunner on earth architecture researches and practices. The DSA program, based on theory and practice researches, started in the 1980s. The yearly international earth festival was initiated in 2000 as a platform for the academic exchange between professionals, professional teaching and universal education. It is because of the professional education provided by CRATerre, professionals of earth architecture have been trained one year after another. One of them established the AKTERRE company especially for the processing, production and sales of materials for earth construction, providing products of various earth for ramming and clay, as well as additives such as gravel, sand, straw etc. Besides, there are some small companies producing components made of earth, such as extruding earth bricks, thermal insulation earth and straw bricks etc. At the same time, with increasingly more demands from the renovation or new projects of the local countryside houses, construction companies specially for earth buildings have emerged, among which CARACOL is a famous earth construction company in France. It has expanded its business to field of earth construction training. Every year they will organize different training programs or lectures for the public. These companies have also set up an association of earth architecture ASTERRE, which hosts conferences regularly in order to acknowledge the latest situations of the industry, exchange engineering technologies and facilitate development.

We can see that after almost forty-year development, the earth architectural industrial in France has taken its shape from the professional construction, professional factories of the engineering aspect to the professional labs of the research aspect and then to the professional educational institutes of the education aspect and the various international exhibitions, forums and exchange events of the promotion aspect. These aspects have covered all areas of earth construction. Even so, it has to be noted that it doesn't mean the earth architecture is in prosperous development in France. In fact earth construction in France is still a minor industry. There is still distance between the application and the ideal objective. It has to be improved technically and popularized.

No doubt that the researches and practical experience of the foreign countries have provided references and directions for the development of the earth architecture in China. Though it is possible to reduce the time for exploration on this basis, the earth architecture as an applied profession has to take its way step by step. In China, not to mention objective of the industrialization and commercialization of earth construction, the concrete construction by now has not reached to the level of the industrialization as the foreign countries. Taking the rammed earth technology as example, the efficiency of installing the formwork and uninstalling it and the strength of the formwork system will greatly influence the cost and quality of ramming. The concrete industrial formwork used by the foreign countries in ramming is not common in the concrete construction in China. The formworks used in China are largely consuming ones. Then taking the rammed earth material as example, the earth construction advocates using local materials. But when the local earth is not suitable for ramming, technologies such as excavation (drying), proportion, mixture are required. More procedures there are, more cost for labor. A large area of site for working and storage is also required. In fact, these were the main two reasons for the lagging behind of the construction process and large cost at the initial phase of the "Tiles Hill" project. Because of the lack of stable earth resources, in the teaching process, it was common to encounter situations like no earth to use or no different earth enough to compare for teaching.



土工业模板，即使在我国的混凝土施工中都极少使用，而是大量使用消耗性模板。再以夯土材料为例，生土建造提倡就地取材，但当当地土质不适于夯土时，土的挖掘（晾晒）、配比、搅拌等技术环节缺一不可，操作环节增多，人工费用增加，还需占据大片作业和存放场地。事实上，这两点正是“水岸山居”夯土工程在初始阶段，施工进度一拖再拖、成本居高不下的主要原因。而由于缺乏稳定的生土来源，在生土的课程教学中，也频频遭遇无土可用、或无土可进行对比教学的尴尬。

综上所述，我认为中国当代生土建筑的发展可以参考法国等国外经验，逐步建立生土建筑产业链，实现生土建造的工业化、产业化和应用的普及性，促进建筑业的可持续性发展。而第一步，正是从示范项目的建设、信息和技术的推广交流做起。王澍教授通过他设计的实际项目和领导的学院教学，已经在这条路上迈开了第一步。我们期待着越来越多的人加入到生土事业中来，发展的脚步可以再快一些，早日让生土建筑的发展达到它应有的地位。

### 5.2 个人今后的生土工作计划

正如前文所言，中国生土建筑具有很大的发展潜力，作为第一个在 CRATerre 受教育的中国学生，我深感自身责任的重大。幸运的是，作为一名建筑专业教师和建筑师，我有机会从事多方面的生土工作。除了在学院的安排下继续生土课程教学和其他相关任务外，还希望能够利用我在法国的学习资源，通过撰写文章介绍国际生土建筑的发展现状，并希望能有幸将 Hugo Houben 和 Hubert Guillaud 的著作《生土建造》（英文版）翻译成中文，借此让更多的专业人士、普通大众了解生土建筑，以此作为我个人所能做的宣传工作。而同时，我希望能有机会切实促成生土建筑项目的实现。比如，正在筹划或运作的云南大理大成村历史文化名村保护开发项目和大理国际文化城项目，除了我本人作为建筑师提供专业技术外，还希望能够促成当地政府和 CRATerre 等国际机构的合作，不仅提高项目专业质量，还将对当地富含生土建筑资源的民居保护、新建建筑项目起到更加广泛和深远的影响，起到示范和引导的作用。

虽然个人的能力有限，但我希望通过我的教学和其他工作，让更多的人了解生土建筑，支持生土建筑，参与到生土事业中来。我衷心希望将来还有机会继续以其他方式向 CRATerre 学习，为中国的生土事业尽一份薄力。

To conclude, I think the development of contemporary earth architecture in China could take the experience of the other countries such as France as reference. The earth architectural industrial chain has to be established increasingly in order to realize the industrialization, commercialization and popularization of the application so that the architectural industry would be developed sustainably. The first step for this must start from the establishment of model project, exchange and promotion of information and technology. Prof. Wang Shu has taken the first step through his design of real projects and establishing the teaching system of the school. We are looking forward to more people joining into this profession and taking quicker steps in order to make the earth architecture get its supposed position soon.

## 5.2 The plan on earth architecture for the future

As stated above, there is great potential for the development of earth architecture in China. As the first Chinese student who receive education in CRATerre, I can feel my responsibility for this. Fortunately, as a teacher of architecture and architect, I have many opportunities to work on earth in many aspects. Besides continuing my teaching and other relative tasks, I also hope that I can take the advantages of my study resources in France, introduce the status of the international earth architecture development by writing papers. I also hope that I would have the honor to translate the English version of *Earth Construction* written by Hugo Houben and Hubert Guillaud into Chinese in order to let more professionals and the common public know about earth architecture. These are what I can do personally as a promotion. At the same time, I hope I will have the opportunity to facilitate the realization of earth building projects, such as the undergoing projects of the historic and cultural village Dacheng in Dali and international cultural city of Dali. In addition to my professional technical support as architect, I also hope that it is possible to make it successful the collaboration between the local government and international institutes as CRATerre. It is not only for promoting the professional quality of the projects, but also will be significantly and widely influential to the preservation of the local folk earth houses and newly built projects, which will be models and instructions for such kind of buildings.

With limited capabilities, I hope, through my teaching and other relative work, I am able to make more people know about earth architecture, support it, join in it. I sincerely hope that I will have opportunities in the future to learn from CRATerre in other ways in order to make contributions to the earth profession in China.

## 附录

附表 1：第一次夯土建造课程进程表（2010.5.31-7.2）

日期	单元教学内容	备 注
2010.5.31 ~6.4	1. 授课：夯筑概述 2. 夯土建筑与夯筑技术调研 3. 夯土墙施工构造设计	伍公山、大井巷、 中山路实地考察
2010.6.5 ~6.9	1. 收集土样及附加材料 • 土样： 每组在杭州市区范围内收集 10 种不同土样，须为可夯筑用土，且方便采土和运输。 收集展示方式： ① 盛器统一：塑料方盘，约 $20 \times 30 \times 5\text{cm}$ ，带盖，且方便摞叠 ② 标签统一：可粘贴标签，约 1cm 高，7~8cm 长 ③ 记录统一：采集地点、时间、人物（照片拍摄） • 土样分布图表： 在地图上标示采样地点且编号 如：A-1, A-2, ..., A-10（附采样地点列表及采样照片） • 附属材料： 如麦秆、竹筋等，同样以方盘装盛，每组 3 种 2. 夯土工具的制备 模板、夯锤、铁铲、土筐等 3. 选定夯筑方案 每小组自选一个夯筑方案，再每两小组共同讨论确定最终的实施方案。 4. 制定夯筑分工计划表 采土、拌土、夯土、工具保管和记录等的分工和施工计划	• 分三个大 组，六个小组， 分工合作。 • 阶段成果汇 报与交流。
2010.6.10 ~6.16	1. 采土 根据施工土量和品种取土，并做好防雨措施 2. 墙脚施工 现浇 25cm 高钢筋混凝土墙脚 3. 夯筑样品实验 制作模板，三个大组按照施工方案分别进行 20cm 立方体夯土块实验。根据实验情况调整施工方案。	• 分三个大 组，六个小组， 分工合作。 • 阶段成果汇 报与交流。
2010.6.17 ~6.29	1. 夯土 成果要求：墙体长 $\times$ 宽 $\times$ 高= $3\text{m} \times 0.35\text{m} \times 2.7\text{m}$ 各组根据施工构造方案，组内分工合作，完成夯土墙体的施工。 夯土墙完成后，清理夯土地地。 2. 夯土过程记录 记录方式： ① 填写施工过程记录表格 ② 整理施工过程记录 ③ 过程照片	• 根据现场状 况，可适当调整 施工方案，改进 施工技术。 • 根据天气情 况，及时调整工 作时间。
2010.6.30 ~7.2	1. 过程记录整理 2. 总结夯土经验 3. 交流夯土经验	三大组课堂交流 夯土经验，并打 分。



## Appendix

**Attached Table 1: Process table for rammed earth course 1 (31/05-02/07/2010)**

Time	Unit Teaching Content	Notes
31/05/2010-04/06/2010	<ol style="list-style-type: none"> <li>Lecture: A brief introduction to ramming</li> <li>Survey on rammed earth construction and technology</li> <li>Structural design for the construction of the rammed earth wall</li> </ol>	Field investigation of Wugong hill, Dajingxiang Lane, Zhongshan Road
05/06/2010-09/06/2010	<ol style="list-style-type: none"> <li>Collection of the earth samples and additive materials <ul style="list-style-type: none"> <li>Sample: <p>Every group is required to collect ten different earth samples within the urban area of Hangzhou. The earth must be feasible for ramming and convenient to collect and transport.</p> <p>Presentation for the collected samples:</p> <ol style="list-style-type: none"> <li>Identical standard of containers: plastic square plate with the size around <math>20 \times 30 \times 5</math> cm, with a lid, convenient to take around.</li> <li>Identical standard of labels: adhesive label, about 1 cm high and 7-8 cm long.</li> <li>Identical standard of records: where, when and who has done the collection (with photos)</li> </ol> <ul style="list-style-type: none"> <li>Diagram for the locations of the samples: <p>Number the location where the sample is collected on the map</p> <p>e.g. A-1, A-2, ..., A-10 (attached with a table for the collection location with sample photos)</p></li> </ul> </li> <li>Additive materials: <p>e.g. wheat straw, bamboo reinforcement, etc. collected in the same kind of square plate, every group has to submit three types</p></li> </ul> </li> <li>preparation of the rammed earth tools <p>formwork, rammer, shovel, basket etc.</p> </li> <li>The final ramming proposal <p>Every team is supposed to choose a proposal and then every two teams to choose the final one.</p> </li> <li>Making a plan for the work division <p>Earth collection, mixing, ramming, tool keeping and recording and the construction plan</p> </li> </ol>	<ul style="list-style-type: none"> <li>Three groups and six sub-divided teams, collaborate together</li> <li>Presentations and communications during every phase</li> </ul>
10/06/2010-16/06/2010	<ol style="list-style-type: none"> <li>Earth collection <p>Collect the earth according to the amount of earth and kind of earth required in the construction; take measures for the rain-proof.</p> </li> <li>Construction of the wall foundation <p>Cast-on-site high steel and concrete foundation of 25 cm height</p> </li> <li>Sample test <p>Making the formwork. Every group is to do a rammed earth test with <math>20 \text{ cm}^3</math> earth cube according to the construction proposal. The proposal has to be adjusted according to the test results.</p> </li> </ol>	<ul style="list-style-type: none"> <li>Three groups and six sub-divided teams, collaborate together</li> <li>Presentations and communications during every phase</li> </ul>
17/06/2010-29/06/2010	<ol style="list-style-type: none"> <li>Earth ramming <p>Requirement of the size: <math>\text{length} \times \text{width} \times \text{height} = 3\text{m} \times 0.35\text{m} \times 2.7\text{m}</math></p> <p>Every group has to collaborate together to finish the construction of the wall according to the proposal and collaborate.</p> <p>After the completion of the wall, the students have to clean up the site.</p> </li> <li>Recording of the whole process <p>Ways of recording:</p> <ol style="list-style-type: none"> <li>Fill the recording table of the construction process</li> <li>Sort out the construction process records</li> <li>Photos of the process</li> </ol> </li> </ol>	<ul style="list-style-type: none"> <li>According to the condition, the proposal could be adjusted and the technology could be improved.</li> <li>According to the climate condition, working time could be adjusted.</li> </ul>

附表 2：第二次夯土建造课程进程表（2011.9.5-10.9）

时间	教学	工作营
第 1 周： 9.5-9.9	<ul style="list-style-type: none"> <li>- 授课               <ul style="list-style-type: none"> <li>○ 生土建筑</li> <li>○ 当代生土建筑</li> <li>○ “生”土材料</li> <li>○ 生土作为一种建筑材料</li> </ul> </li> <li>- 练习               <ul style="list-style-type: none"> <li>○ 夯土建造流线</li> <li>○ 金工实验室夯土墙建造流线设计</li> </ul> </li> <li>- 实践               <ul style="list-style-type: none"> <li>○ 原有夯土墙体的观察：缺点和优点</li> <li>○ 野外测试的示范：沉淀测试、触摸和手洗测试</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- 参观               <ul style="list-style-type: none"> <li>○ 杭州附近几个可能的采土点的参观：烧砖厂，采石场和校园内的建筑工地。</li> <li>○ 采土点现场的野外测试，以了解生土的基本性质。</li> <li>○ 为进一步的实验室测试采集土样。</li> </ul> </li> <li>- 夯土建造               <ul style="list-style-type: none"> <li>○ 拆除场地上的原有夯土墙，清理建造场地。</li> <li>○ 与基建处何工的第一次关于模板设计的讨论，选择了垂直向移动的整体模板系统。</li> </ul> </li> </ul>
第2周： 9.12-9.16	<ul style="list-style-type: none"> <li>- 练习               <ul style="list-style-type: none"> <li>○ 夯土建造流线的作业成果汇报</li> <li>○ 完善作业成果，共同完成一份包含所有要点的建造组织计划文本：建筑平面、所需材料及其数量、建造流线的设计、施工工具、人员分组和建造进程表。</li> </ul> </li> <li>- 实践               <ul style="list-style-type: none"> <li>○ 不同含水率下土的五种状态</li> <li>○ 夯筑教学试验墙</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- 夯土建造               <ul style="list-style-type: none"> <li>○ 建造组织：列设备工具清单</li> <li>○ 第一次送达生土（土、砂、石）</li> </ul> </li> </ul>
第 3 周： 9.19-9.23	<ul style="list-style-type: none"> <li>- 实践               <ul style="list-style-type: none"> <li>○ 继续夯筑教学试验墙</li> <li>○ 测试第一种配比混合土</li> <li>○ 用 Proctor 试验测试同种配比混合土</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- 夯土建造               <ul style="list-style-type: none"> <li>○ 混凝土基座的建造</li> <li>○ 第一次和第二次送土，送来两种不同的土，而且都与第一周送来的土样不同。</li> <li>○ 新一轮模板的讨论以改进设计</li> </ul> </li> </ul>
第4周： 9.26-9.30	<ul style="list-style-type: none"> <li>- 实践               <ul style="list-style-type: none"> <li>○ 由于下雨，教学试验的夯筑被迫停止</li> <li>○ 制作压实试验用的模具</li> <li>○ Proctor 试验</li> <li>○ 筛分和配比练习</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- 夯土建造               <ul style="list-style-type: none"> <li>○ 购买工具</li> <li>○ 与施工队确认模板的制作</li> </ul> </li> </ul>
第 5 周： 10.8-10.9	<ul style="list-style-type: none"> <li>- 实践               <ul style="list-style-type: none"> <li>○ 在建造实验室用青砖砌筑夯土墙基座。这堵墙体将用作以当地不同颜色的土进行墙面纹理的试验。</li> <li>○ 筛分和配比练习</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>- 夯土建造               <ul style="list-style-type: none"> <li>○ 施工队搭建模板</li> <li>○ 大量生土送达</li> </ul> </li> </ul>

30/06/2010-02/07/2010	<ol style="list-style-type: none"> <li>1. Sort out the process records</li> <li>2. Summary of the ramming experience</li> <li>3. Communication of the ramming experience</li> </ol>	The three groups are supposed to communicate their ramming experience in a seminar and will get a score for each group.
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**Attached Table 2: Process table of rammed earth course 2 (05/09-09/10/2011)**

TIME	TEACHING	WORKSHOP
Week 1: 05-09 September	<b>- Lessons:</b> <ul style="list-style-type: none"> <li>o Earthen architecture</li> <li>o Contemporary earthen architecture</li> <li>o Earth as a raw material</li> <li>o Earth as a building material</li> </ul> <b>- Exercises:</b> <ul style="list-style-type: none"> <li>o Rammed earth production line</li> <li>o Design of the production line for the construction of a metal workshop made of rammed earth</li> </ul> <b>- Practice:</b> <ul style="list-style-type: none"> <li>o Observations on the existing rammed earth walls: weaknesses and strengths</li> <li>o Demonstration of some field tests: bottle test, touch test and hand washing test</li> </ul>	<b>- Visits:</b> <ul style="list-style-type: none"> <li>o Visits of different potential extraction sites around Hangzhou: a cooked brick factory, a sand and gravel quarry and a building site on the campus.</li> <li>o Field tests on the different sites in order to have a first idea on the different materials available.</li> <li>o Sample collecting for future analysis in the laboratory.</li> </ul> <b>- Metal workshop:</b> <ul style="list-style-type: none"> <li>o Destruction of the existing rammed earth walls to free the space for the future metal construction workshop.</li> <li>o First meeting with the CAA engineers to discuss the design of the formworks. The integral formworks with vertical progression have been chosen.</li> </ul>
Week 2: 12-16 September	<b>- Exercises:</b> <ul style="list-style-type: none"> <li>o Presentation of the students works on the production line.</li> <li>o Common correction in order to set up on single file containing all the needed information: the plan of the building, the needed materials, the production line, the needed tools, a construction agenda and the teams schedule.</li> </ul> <b>- Practice:</b> <ul style="list-style-type: none"> <li>o The five hydric states of earth</li> <li>o Construction of the pedagogic rammed earth wall</li> </ul>	<b>- Metal workshop:</b> <ul style="list-style-type: none"> <li>o Organising the future construction: listing the available tools and equipment</li> <li>o First command of raw materials (earth, sand and gravel)</li> </ul>
Week 3: 19-23 September	<b>- Practice:</b> <ul style="list-style-type: none"> <li>o Continuing the construction of the rammed earth pedagogic wall</li> <li>o Testing a first reformulated earth mixture</li> <li>o Testing the same reformulation with the Proctor test</li> </ul>	<b>- Metal workshop:</b> <ul style="list-style-type: none"> <li>o Construction of the concrete basements</li> <li>o First and second delivery of two different earths, each different from the sample collected during the first week.</li> <li>o New discussion on the formworks to improve their design.</li> </ul>
Week 4: 26-30 September	<b>- Practice:</b> <ul style="list-style-type: none"> <li>o Rain: the construction of the rammed earth pedagogic wall is stoped</li> <li>o Construction of moulds for the compaction test</li> <li>o Proctor test</li> <li>o Sieving and reformulation exercise</li> </ul>	<b>- Metal workshop:</b> <ul style="list-style-type: none"> <li>o Buying the necessary tools</li> <li>o Meeting with the building company to check on the construction of the formworks. The delivery has been set up for the end of the week</li> </ul>
Week 5: 08-09 October	<b>- Practice:</b> <ul style="list-style-type: none"> <li>o Construction of a rammed earth wall basement inside the construction laboratory with some cooked bricks. This future wall will allow to experiment the aesthetic potential of the local earth.</li> <li>o Sieving and reformulation exercise</li> </ul>	<b>- Metal workshop:</b> <ul style="list-style-type: none"> <li>o Installing the formwork by the building company</li> <li>o Delivery of an important quantity of earth</li> </ul>



附表 3：第三次夯土建造课程计划表（2012.5.28-6.29）

时间			教学环节	内容	作业	备注
第1周	星期一	13:00-14:30	理论授课	生土建筑与夯土建筑	夯土建造调研	1) 学生共62人, 分成6组, 编号A-F。 2) 在各教学环节中, 以组为单位完成各项任务。 3) 在建造和试验环节, ABC三组和DEF三组错开, 轮换进行现场的建造或实验室的试验。 4) 组内成员自行分工, 制定分工计划表。
		14:30-16:00	参观调研	“水岸山居”夯土施工现场		
	星期三	13:00-14:30	理论授课	传统夯土与现代夯土	夯土建造流线设计	
		14:30-16:00	参观调研	“金工实验室”夯土施工现场		
	星期五	13:00-16:00	汇报交流	建造流线(金工实验室/试验墙)	夯土建造流线设计修改	
第2周	星期一	13:00-16:00	建造实践	金工实验室施工*/试验墙①*	技术环节记录	
	星期三	13:00-16:00	建造实践	金工实验室施工/试验墙①	技术环节记录	
	星期五	13:00-16:00	建造实践	金工实验室施工/试验墙①	夯土技术总结	
第3周	星期一	13:00-14:30	汇报交流	现场的墙体施工比较	施工技术比较	
		14:30-16:00	试验示范	夯土比较试验*		
	星期三	13:00-16:00	试验操作/建造实践	夯土比较试验/金工实验室施工	实验结果记录/技术环节记录	
	星期五	13:00-16:00	试验操作/建造实践	夯土比较试验/金工实验室施工	实验结果记录/技术环节记录	
第4周	星期一	13:00-16:00	理论授课与演示	生土材料与夯土技术	夯土技术总结修改	
	星期三	13:00-16:00	建造实践	金工实验室施工/试验墙②*	技术环节记录	
	星期五	13:00-16:00	建造实践	金工实验室施工/试验墙②	技术环节记录	
第5周	星期一	13:00-16:00	建造实践	金工实验室施工/试验墙②	技术环节记录	
	星期三	13:00-16:00	建造实践	金工实验室施工/试验墙②	课程总结	
	星期五	13:00-16:00	汇报交流	课程总结	成果汇总	

\*注:

夯土比较试验: 指颗粒配比比较试验、Proctor击实比较试验和分层击实比较试验等三个直观体现夯土关键技术的试验。

试验墙①: 不同材料配比的夯土墙试验, 分别为纯土、土石混合土和土砂石混合土。使用传统模板和木夯锤, 体验夯土建造。  
试验墙②: 经合理配比的混合土夯土墙试验, 保证夯土质量的同时, 进行墙面色彩、机理等的尝试。使用现代模板和气动夯锤, 完成高质量的夯土墙建造。

金工实验室施工: 现场的施工需根据工程进展, 进行夯土建造, 或配合工人进行木构架、屋顶和门窗等的制作和装配。

**Attached Table 3: Schedule of rammed earth course 3 (29/06-28/05/2012)**

Time			Phase	Content	Assignment	Notes
Week 1	Monday	13:00-14:30	Theory lecture	Earth & rammed earth architecture	Investigation of the rammed earth construction	1 ) The 62 students will be divided into six teams, numbered as A-F. 2 ) In every teaching phase, the students will finish every task as teams. 3 ) In the construction and testing phases, team A,B,C and team D,E,F will take in turns to do the construction on site or testing in the lab. 4 ) The members of each team will divide the work by themselves, making a work division table.
		14:30-16:00	Visit and survey	Site visit of the "Tiles Hill" project		
	Wednesday	13:00-14:30	Theory lecture	Traditional & modern rammed earth	Production line design of the rammed earth construction	
		14:30-16:00	Visit and survey	Site visit of the "metalworking lab" project		
	Friday	13:00-16:00	Presentation	Production line (metalworking lab/Experimental wall )	Adjustment of the production line design	
Week 2	Monday	13:00-16:00	Construction practice	Construction of the metalworking lab*/Experimental wall①*	Recording of the technology	
	Wednesday	13:00-16:00	Construction practice	Construction of the metalworking lab/Experimental wall①	Recording of the technology	
	Friday	13:00-16:00	Construction practice	Construction of the metalworking lab/Experimental wall①	Summary of the ramming technology	
Week 3	Monday	13:00-14:30	Presentation & communication	Comparison of the wall construction on site	Comparison of the ramming technology	
		14:30-16:00	Testing model	Comparison test of the rammed earth*		
	Wednesday	13:00-16:00	testing operation/construction prtctice	Comparison test of the rammed earth/Construction of the metalworking lab	Testing results records/Technology records	
	Friday	13:00-16:00	testing operation/construction prtctice	Comparison test of the rammed earth/Construction of the metalworking lab	Testing results records/Technology records	
Week 4	Monday	13:00-16:00	Lectures and presentation	Rammed earth materials and ramming technology	Summary adjustment of the ramming technolgoy	
	Wednesday	13:00-16:00	Construction practice	Construction of the metalworking lab/Experimental wall②*	Recording of the technology	
	Friday	13:00-16:00	Construction practice	Construction of the metalworking lab/Experimental wall②	Recording of the technology	
Week 5	Monday	13:00-16:00	Construction practice	Construction of the metalworking lab/Experimental wall②	Recording of the technology	
	Wednesday	13:00-16:00	Construction practice	Construction of the metalworking lab/Experimental wall②	Summary	
	Friday	13:00-16:00	Presentation & communication	Summary	Collection of the results	

\*ps;

Rammed earth comparison tests refer to the three intuitive key technical tests including the granular proportion comparison test, proctor test and layered ramming comparison test.

Experimental wall①: tests for rammed earth walls with different proportional materials, namely pure earth, mixture of earth and stone and mixture of earth and sand. The students experience construction with tools such as traditional formwork and wooden rammer.

Experimental wall②: the earth mixture with the optimal proportion gain from the test will ensure the quality of the rammed earth and enable more attempts on the surface color and texture.

Construction for the metalworking lab: the construction has to be preceded according to the project process, or coordinated with the workers for the production and fixing of the wooden structure, roof, door and windows.

附表 4：夯土建造课程调查表

夯土建造课程调查表

填表需求：此调查将用于改进教学，了解建筑学专业学生对生土建筑的观点，以关注生土建筑的发展。请客观认真地填写，谢谢！

年级：性别：填表日期：

关于教学效果

1 课程之前，你对生土建筑或夯土建造有所了解吗？

A 没听说过 B 有一点 C 了解

2 课程之前，你对生土建筑有学习的愿望吗？

A 没有 B 有一点 C 有

3 课程之后，你觉得课程达到了你的期望吗？

A 没有 B 不完全达到 C 达到

4 如果你认为教学效果不够好，是哪方面的原因造成的呢？

A 授课方式 B 课程设置 C 个人原因

5 通过课程，你对生土建筑或夯土建造感兴趣吗？

A 不感兴趣 B 有点兴趣 C 挺有兴趣

6 你认为此课程对你的专业学习有帮助吗？

A 没有 B 有一点 C 有

关于课程设置

7 你觉得对你有帮助最大的是哪个教学环节？

A 理论授课 B 实验操作 C 建造实践

8 你最不感兴趣的是哪个教学环节？

A 理论授课 B 实验操作 C 建造实践

9 你对此课程的设置有哪些建议或意见：  
(如课时安排、授课方式、作业强度...)

关于生土事业

10 你希望将来从事与生土建筑有关的工作吗？(新建、保护等)

A 不想 B 无所谓 C 希望

11 作为未来的建筑师，你希望在今后的工作中使用生土建造吗？

A 不想 B 根据情况 C 创造机会也要用

12 如果不想，主要的原因是

13 如果希望，主要的原因是

14 如果希望，你觉得有必要进一步学习有关知识和技术吗？

A 不需要 B 根据情况 C 需要

15 作为使用者，你愿意长期居住或工作在生土建筑中吗？

A 不愿意 B 无所谓 C 很愿意

如果你还有想说的，请写在这里：

谢谢你的合作！

98

DSA-TERRE 2010-2012 毕业论文



**Attached Table 4: Feedback Survey Questionnaire of the Rammed Earth Construction Course****Feedback Survey Questionnaire of the Rammed Earth Construction Course**

Notice: this questionnaire is used to improve teaching and get to know the view of students of architecture major toward earthen architecture in order to focus on the development of earthen architecture. Please fill it sincerely and objectively. Thank you!

Grade: \_\_\_\_\_ Sex : \_\_\_\_\_ Date : \_\_\_\_\_

**About teaching effect**

- |   |   |                       |                       |                    |
|---|---|-----------------------|-----------------------|--------------------|
| 1 | Before the course, did you know anything about earthen architecture or rammed earth construction? | A Never               | B A little            | C Definitely yes   |
| 2 | Before the course, did you have any willingness to learn earthen architecture?                    | A Never               | B A little            | C Definitely yes   |
| 3 | After the course, do you think it is within your expectation?                                     | A Never               | B Not so much         | C Definitely yes   |
| 4 | If you think the teaching effect is not good enough, which aspects had contributed to this?       | A The way of teaching | B Course organization | C Personal reasons |
| 5 | Are you interested in earthen architecture or rammed earth construction after the course?         | A Not at all          | B A little            | C Quite a bit      |
| 6 | Do you think the course is helpful to your architectural study?                                   | A Not at all          | B A little            | C Definitely yes   |
- Please elaborate: \_\_\_\_\_
- 
- About the course organization**
- |   |   |                   |             |              |                         |
|---|---|-------------------|-------------|--------------|-------------------------|
| 7 | Which step do you think is most helpful to you? | A Theory lectures | B operation | Experimental | C Construction practice |
| 8 | Which step are you mostly uninterested?         | A Theory lectures | B operation | Experimental | C Construction practice |
- Do you have any suggestions for the course organization: \_\_\_\_\_
- ( such as arrangement, way of teaching, assignment, etc. ) \_\_\_\_\_

**About earth profession**

- |    |   |      |               |  |
|----|---|------|---------------|--|
| 10 | Do you want to be involved in the earthen architecture in the future?(new or preservation etc.) | A No | B Don't care  | C Hope so                                  |
| 11 | As a future architect, do you want to use earthen construction in the future work?              | A No | B Accordingly | C Yes, even I have to create opportunities |
| 12 | If you don't, what is the main reason _____   |      |               |  |
| 13 | If you do, what is the main reason _____  |      |               |  |
| 14 | If you do, do you think it is necessary to learn further knowledge and skills?                  | A No | B Accordingly | C Yes                                      |
| 15 | As a user, do you like to live or work in earthen buildings for long period?                    | A No | B Don't care  | C Yes                                      |

If you have anything to say, please write here: \_\_\_\_\_

Thanks for your cooperation !

附表 5：夯土建造课程调查结果统计表

调查结果	选项计数			选项比例		
选项	A	B	C	A	B	C
建筑艺术系09级（参加第一次夯土建造课程），共61人，参加调查人数43人。						
1	8	32	3	19%	74%	7%
2	9	13	21	21%	30%	49%
3	4	22	17	9%	51%	40%
4	5	30	6	12%	70%	14%
5	1	12	29	2%	28%	67%
6	0	9	33	0%	21%	77%
7	3	7	32	7%	16%	74%
8	24	9	5	56%	21%	12%
10	6	17	20	14%	40%	47%
11	1	31	11	2%	72%	26%
14	0	10	33	0%	23%	77%
15	8	22	13	19%	51%	30%
建筑艺术系08级（参加第二次夯土建造课程），共41人，参加调查人数16人。						
1	0	16	0	0%	100%	0%
2	4	5	7	25%	31%	44%
3	2	11	3	13%	69%	19%
4	5	10	1	31%	63%	6%
5	1	8	7	6%	50%	44%
6	0	8	7	0%	50%	44%
7	1	6	9	6%	38%	56%
8	6	6	2	38%	38%	13%
10	3	7	6	19%	44%	38%
11	0	16	0	0%	100%	0%
14	0	5	11	0%	31%	69%
15	5	6	5	31%	38%	31%

**Attached Table 5: Statistics of the Survey of the Rammed Earth Construction Course**

RESULTS	OPTION COUNT			OPTION PROPORTION		
OPTION	A	B	C	A	B	C
09 Grade students (course 1) , 43 students involved (a total of 61)						
1	8	32	3	19%	74%	7%
2	9	13	21	21%	30%	49%
3	4	22	17	9%	51%	40%
4	5	30	6	12%	70%	14%
5	1	12	29	2%	28%	67%
6	0	9	33	0%	21%	77%
7	3	7	32	7%	16%	74%
8	24	9	5	56%	21%	12%
10	6	17	20	14%	40%	47%
11	1	31	11	2%	72%	26%
14	0	10	33	0%	23%	77%
15	8	22	13	19%	51%	30%
08 Grade students (course 2), 16 students involved (a total of 41)						
1	0	16	0	0%	100%	0%
2	4	5	7	25%	31%	44%
3	2	11	3	13%	69%	19%
4	5	10	1	31%	63%	6%
5	1	8	7	6%	50%	44%
6	0	8	7	0%	50%	44%
7	1	6	9	6%	38%	56%
8	6	6	2	38%	38%	13%
10	3	7	6	19%	44%	38%
11	0	16	0	0%	100%	0%
14	0	5	11	0%	31%	69%
15	5	6	5	31%	38%	31%

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## 后记

本文作为我攻读 DSA-Terre 课程的学位论文，首先要感谢王澍和陆文宇教授的支持。没有王澍教授的高瞻远瞩，指引我的研究方向，并派我到法国进修，我不会进入到生土建筑的研究领域，更没有机会进入国际最先进的生土建筑教育机构 CRATerre 进修学习。

在 CRATerre 的学习过程是令人终生难忘的，不仅仅缘于这是一次异国求学的经历，更在于整个教学过程中科学严整的课程设置，负责严谨的教师和认真好学的同学，尤其是他们对生土事业的执着和热情，都给我这个身为“教师”的学生留下了极为深刻的印象。尽管由于我不通法语，必然影响课程学习效果，但这并不影响我感受到 CRATerre 乃至法国的学者做学问严谨的态度和方法。这一点，更让我受益匪浅！

本文的写作首先要感谢 Anne-Monique Bardagot 教授的指导，尤其是她在杭州期间，针对我实习期的实际工作调整了论文的研究方向。在具体的写作内容和结构上，Thierry Joffroy 教授则给予了十分有益的建议，让本文更加充实，更加具有现实的参考意义。

这里，还要着重感谢 Marc Auzet 在我求学过程中给予的帮助。作为同学，他承担起用英文为我翻译讲解课程内容的任务。如果没有他耐心准确的讲解，难以想象我能够顺利完成在法六个多月的学业。除了他，还有许多同学，如 Juliette、Alina、Peulo、Suilan 等也都在不同程度上给予我学习上的帮助，生活上的关心和关照；Bako Rakotomamonjy 则不厌其烦地单独为我用英语解释学业上的各工作事项；而 Mathilde Beguin 作为我的老师和同屋，还带我参加和体验 CARACOL 生土建造公司的生土培训和日常工作，是我除了 DSA 课程外，一个重要的学习补充和经历。在此，一并表示衷心的感谢！

在中国美术学院的工作和实习期间，作为同事的 Marc 和 Juliette，同样在工作中给予我很大的帮助。事实上，本文中第二次课程的记录部分和实验室建设的部分内容参考了他们的工作报告。实验室里，他们勤奋严谨的工作给我院的师生留下了深刻的印象。此外，还要感谢陈家辉老师，他为配合实验室的建设和夯土课程的教学付出了辛勤的劳动；实验室的新成员魏超超，通过自身的努力和勤奋，他已成为生土建筑实验室开展各项工作的得力助手；还有就是在教学和培训过程中，积极参与并为实验室工作做出贡献的研究生李恩赐、周功钊等。

本文由我中文写作，同事张敏敏翻译。感谢她牺牲业余时间提供的及时准确的翻译，使本文得以按时完成。

当然，最重要的是感谢我的家人。我的丈夫林挺，也是同事，他不但理解我的生土工作，还在实际行动上支持这一事业。事实上，正是他在积极努力地促成云南大理的生土项目。

回首从事生土工作的这两年多，在工作和学习中给过我帮助的人实在很多，无法一一列举。生土建筑是一项贴近民众、关乎民生的事业，需要更多的人的参与。希望我的工作也能够为中国的生土建筑事业提供一份哪怕是微小但切实的帮助！

张 雯

2012.6.11 于杭州

## Postscript

This text is my thesis for the degree of DSA-Terre program. First of all, I want to express my gratefulness to the support of Prof. Wang Shu and Lu Wenyu. Without Prof. Wang Shu's foresight as the orientation of my research and his decision to send me to participate the program, I would not have the opportunity to enter into the research area, or even be admitted to CRATerre the most advanced institution on earth architecture education internationally.

My study experience in CRATerre is so impressed that I would remember it for my whole lifetime. It is not only because that this is a study experience abroad, but also because that I, as a student and a "teacher", am deeply impressed by the scientific and strict curriculum setting, thoughtful teachers, and diligent students. Though I don't know French, which certainly affect my learning to some extent, this is not an obstacle for me to feel the serious attitudes and methods of the CRATerre and the French scholars. I have benefited a lot from this.

As for the writing of this thesis, firstly I want to thank Prof. Anne-Monique Bardagot for her instruction, especially during her stay in Hangzhou when she helped me adjust the research direction of this thesis according to the work I was doing for my internship. While Prof. Thierry Joffroy gave me helpful suggestions for the content and structure of the thesis, which has made it richer in content and more useful for real operation.

I also want to thank Marc Auzet for his help during my study process. As classmate, he translated the main content of the French courses into English. Without his patient and specific explanation, I couldn't imagine how I shall finish the six-month study program in France. Besides, there were many classmates who have helped me somehow in my study and taken care of me during my stay in France, such as Juliette, Alina, Peulo, Suilan; Bako Rakotomamonjy patiently explained to me every working procedure in English; Mathilde Beguin, as my teacher and roommate, took me to experience the earth training and daily work in CARACOL, which was an important complementary study experience additional to DSA courses. I am thankful to all these persons!

During the work and internship in China Academy of Art, Marc and Juliette, as my colleagues also helped me greatly. In fact, the recording part of the second course and part of the establishment of the lab in this thesis took reference to their working report. Their diligent and serious working attitude impressed the teachers and students in our school deeply. Besides, I also want to thank Mr. Chen Jiahui, who worked hard to coordinate the establishment of the lab and the rammed earth course; to the new staff member of the lab Wei Chaochao, who has become a helpful hand for the all kinds of work of the SCL with his personal efforts and hardworking; also to the postgraduates students Li Enci, Zhou Gongzhou etc., who participated and contributed to the work of the lab in the teaching and training process.

I wrote the thesis in Chinese and my colleague Zhang Minmin translated it. Thanks to her sacrificing of her spare time for this work and the accurate translation, the thesis could be finished on time.

Of course, the most important persons I want to thank are my family. My husband Lin Ting, who is also my colleague, understands my work on earth and also supports me on my work. As a matter of fact, it is he who is making great efforts to facilitate the realization of the earth project in Dali, Yunnan province.

Recalling the two-year experience in working with earth, there are so many people who have helped me that I can't list all their names here. Earth architecture is a career close to and caring for the common public, which need more people be involved into. I hope that my work will contribute to the earth architecture in China, even little but practical contribution.

Zhang Wen

11 June, 2012, in Hangzhou