RAMMED EARTH ARCHITECTURE

夯土建筑

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WORKSHOP REPORT
工作营报告

6/24/15 - 6/30/15

FOREWORD

In 2014, a magnitude 6.5 earthquake struck the Ludian County in the Yunnan province of China. The earthquake has claimed 617 lives. 112 people were reported missing, at least 3000 people were injured. Over 80,900 houses collapsed and 129,100 were severely damaged.

前言

2014年，一个强度6.5级的地震发生于云南省的鲁甸县。地震导致617人死亡，112人失踪，3千多人受伤。超过8.09万个房屋倒塌，12万9千多间房屋严重受破坏。

photo: www.news.yahoo.com

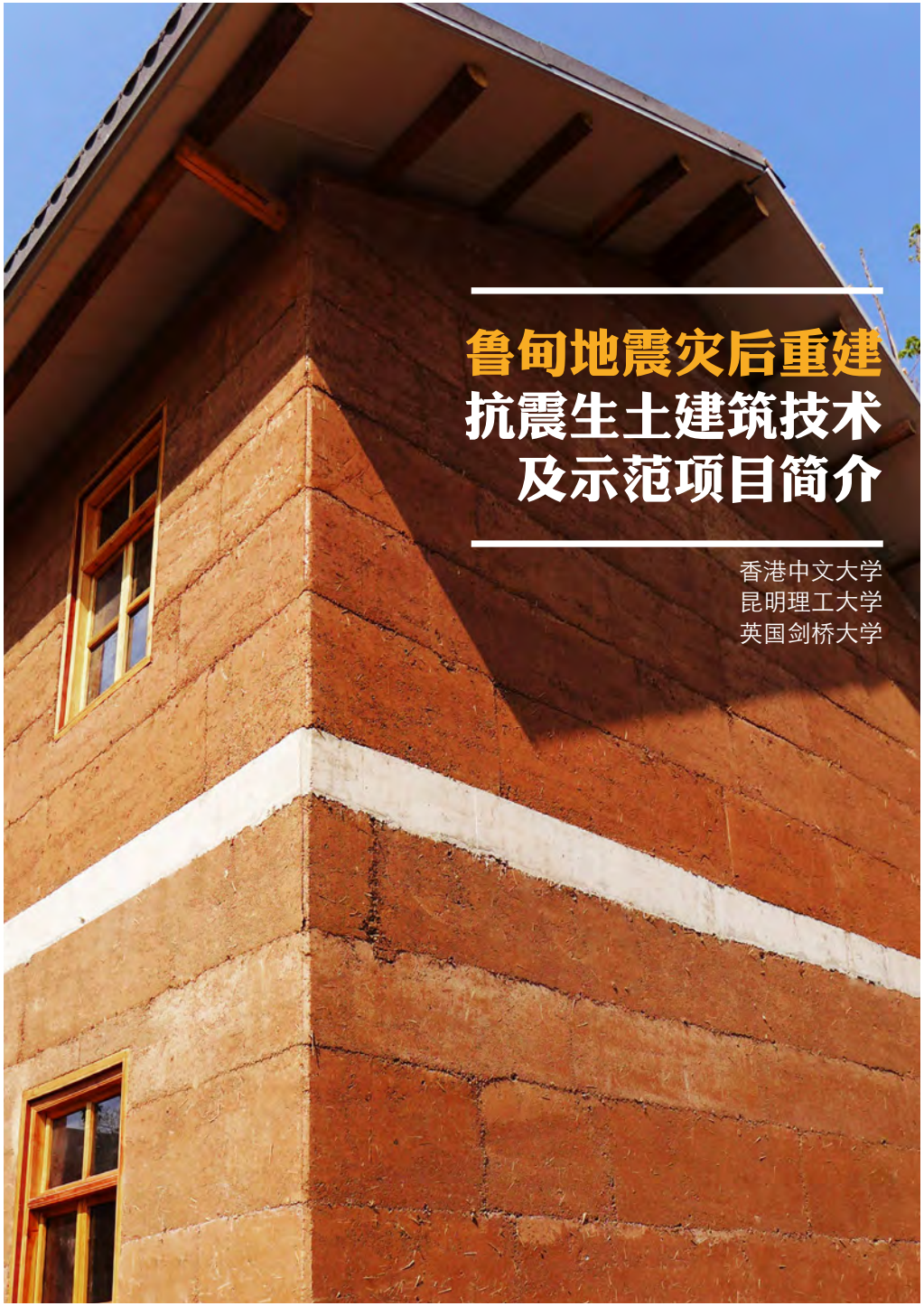
FOLLOW-UP 跟进

Team members from The Chinese University of Hong Kong, Kunming University of Science and Technology and University of Cambridge had a visit to Guangming Village, one of the affected villages. After a detailed investigation, the team decided to launch a village re-building assistance programme in Guangming Village in late Oct 2014 and planned to rebuild the 1st demonstration village house within 3 months.

由中大、昆明理工及劍橋大學組成的團隊於2014年10月下旬到訪光明村，經詳細考察後，團隊決定為當地村民展開一個農村災後重建項目，並定下時間表，計劃在3個月內先完成第一戶示範房屋。

Below: Demonstration House
Right: construction manual written by the team summarizing their experiences
下图: 示范房屋
右图: 团队总结经验后编写的手册

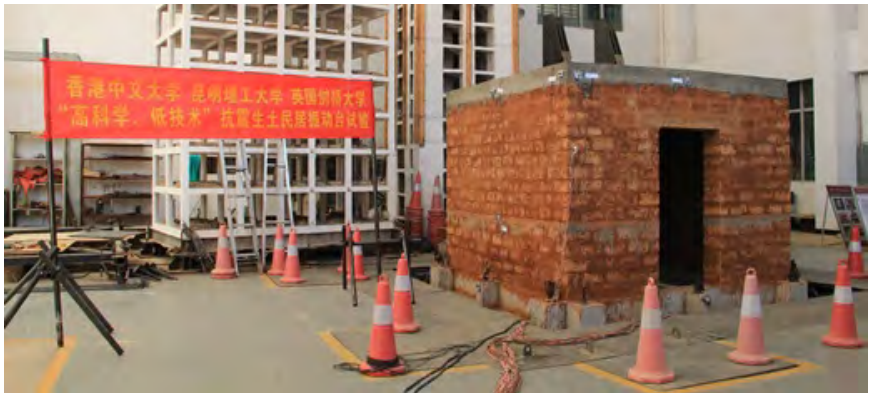
Photos and Text: www.1u1v.org



EXPERIMENT 实验

In mid Jan, 2015, the team conducted an anti-seismic testing for 1:1 abode brick wall and rammed earth wall. The test proves that their structures have good anti-seismic performance.

團隊於2015年1月中旬在昆明理工大學抗震試驗所進行了土坯牆和夯土牆的地震模擬震動臺實驗。本次實驗是利用改進過後的夯土技術建造1:1模型。實驗結果表明，該技術具有良好的抗震性能。



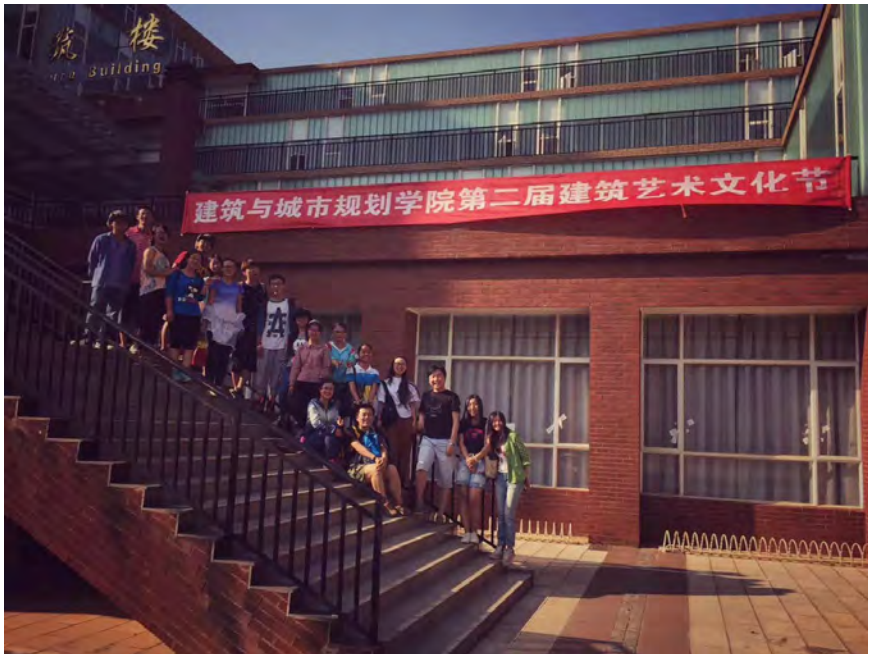
Photos and Text: www.1u1v.org

WORKSHOP 工作营
6/24/15 – 6/30/15

To further investigate anti-seismic rammed earth architecture, Kunming University of Science and Technology and the Chinese University of Hong Kong organized a 1-week workshop that involved student participants from both campuses. The workshop's goal is to provide to students a hands-on experience on the design and construction of rammed earth structure. The students were divided into 3 teams with various mission: rammed earth team, roofing team, and interior team.

为了更进一步了解抗震夯土技术，昆明理工大学和香港中文大学一起举办了为期一周的工作营。这个工作营提供了机会让两个校园的学生一起去设计和实地建造夯土结构。学生分成了三个小组：夯土组，屋顶组，和室内组。

Below: Location of workshop, Kunming University of Science and Technology
下图: 工作营地点，昆明理工大学



PROJECT SITE 选址

The space adjacent to the experimental structures (red marker) was selected as the project site for the rammed earth team. The team's mission was to design two rammed earth walls that have improved thermal properties and special functions.

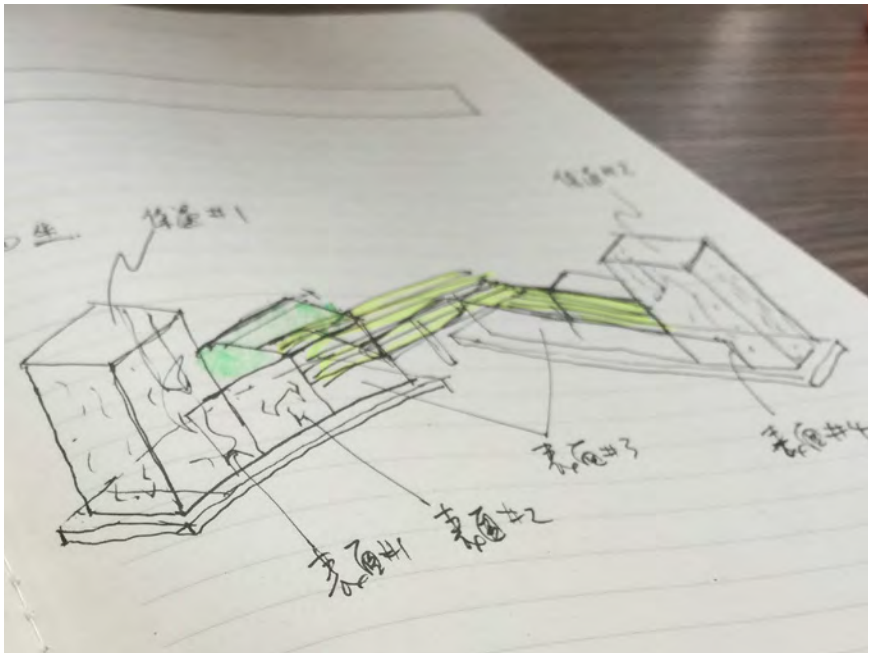
实验结构旁边的空地（红色标志）被选为夯土组的选址。该组的任务是要设计两道有保温性能和有特别功能的夯土墙。

The site already came with existing foundations as students have carried out other experiments in that area before. For the sake of simplicity the new structures would be constructed on top of these foundations.

因该空间之前是其他实验的选址，所以已有地基。为了保持建造的简单和可行性，新的夯土结构将会建造在现有地基之上。

Below: 2nd year students taking site measurements
下图: 大二学生实地测量

DESIGN 设计



Since we had a tight schedule, and most of us had little to no experience with rammed earth architecture, we took the advice of our consultant (an older student who's thesis is about rammed earth architecture) and decided to keep most of the design simple and focus on only a few detail. We decided to design 2 walls that would 1) exhibit different patterns, 2) have thermal layers made of recycled/sustainable materials, and 3) have special functions that repond to the views of the site.

由于工作营时间有限，加上夯土组大部分成员没有夯土方面的经验和知识，我们接纳了我们顾问（一个毕业论文是关于夯土建筑的毕业生）的建议，保持整体设计简单，并把注意力放在几个细节上。我们最后决定设计两道墙，它们的功能有：1）不同的纹理，2）用循环再用 / 环保的保温材料，3）特别功能和选址景观有关。

FEASIBILITY 可行性

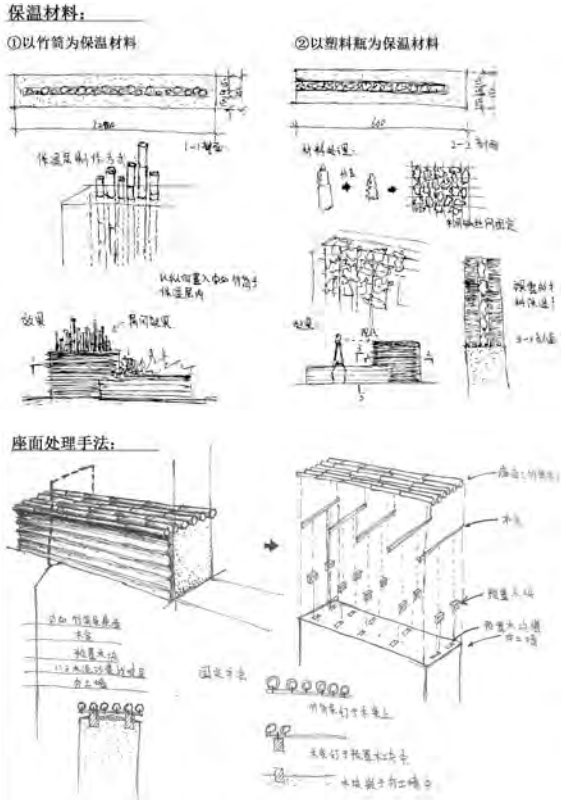
Feasibility was also one of the major deciding factors. As we went through rounds of design we constantly consider if our design is buildable for us in a few days. Construction detail and building process were discussed from early-on as a result. To the 2nd year students (which made up most of the team) who had yet to build something bigger than the models of their projects, this was a very good exercise to understand what it takes to make designs happen in real life.

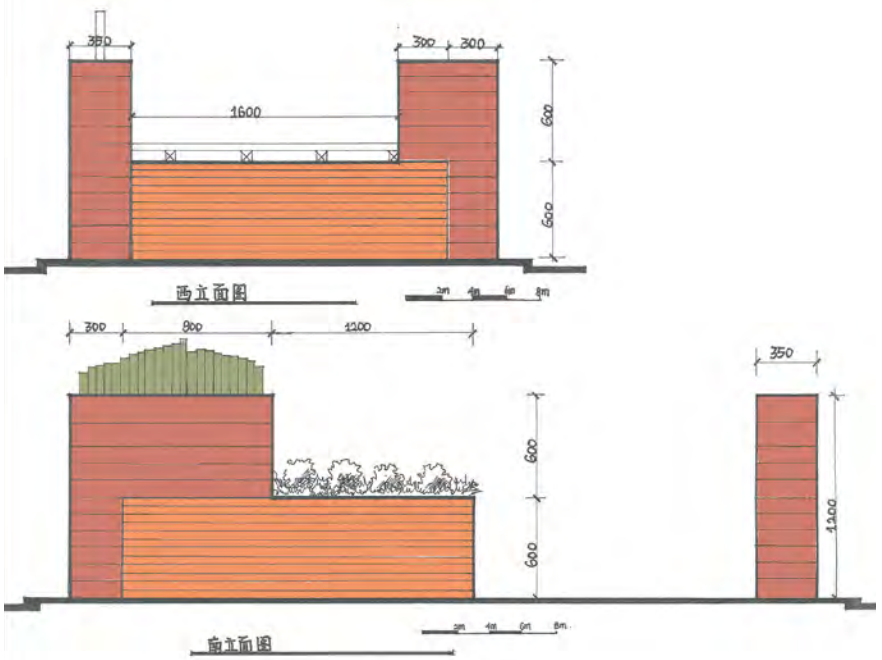
可行性是其中一个最重要的因素。我们在设计的过程中不停的在考虑我们的设计是否能够在几天时间内建成。因此，建造细节和过程在一开始已被讨论和考虑。这个过程对并没有建造过比建筑模型更大的大二学生（团队的大多数）来说是一个很好的练习，因为在这个过程里他们能够体会到要把设计实现是需要考虑的因素之多。

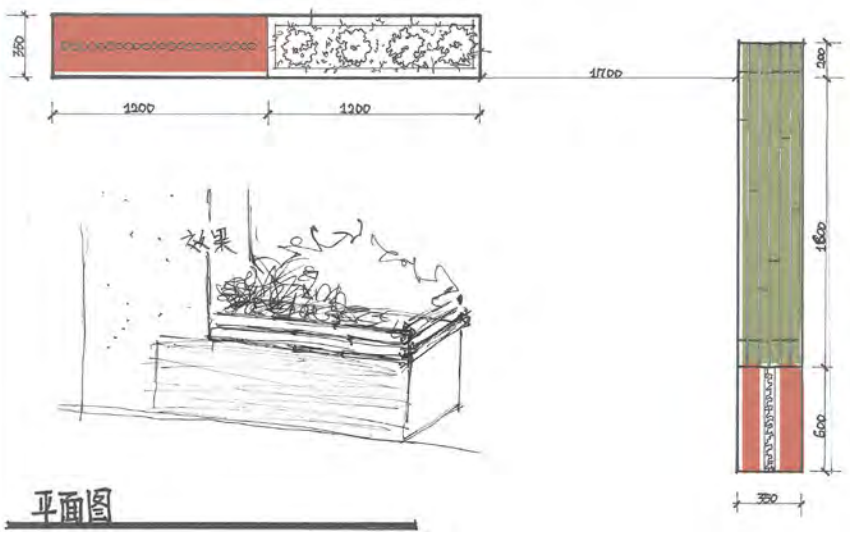
FINAL PROPOSAL 最终方案

The final proposal consists of two mirroring walls. The mirrored design was selected for its construction efficiency as the construction process can be duplicated. Each wall consists a thermal barrier made of recycled/sustainable materials, plus a special feature such as a plantation or a seating area that responds to the site's views.

最终设计方案包括两道形状相反的墙。这个形状相反的设计能提高建造效率，因为他们的建造过程是一样的。每一道墙都有使用环保物料的保温层。对应着选址的景观，每道墙也会有一个花槽或者是座椅。







TRIAL BUILD 建造试验

The team decided to carry out a trial build to test out some of the ideas, such as the use of empty water bottle as a thermal barrier, the use of bamboo strips as a form work, and also to figure out the right earth recipe.

夯土组也决定进行一个建造试验来测试一些设计想法，例如：使用空塑料水平做保温层，使用竹片来当模板，还有寻找最适合的土料配方。

Upper Left: Using the alloy mold for the first time
Middle Left: Filtering and moving earth
Lower Left: Trying out different earth recipes

左上：第一次组装合金模板
左中：筛土和运土
左下：尝试不同的土料配方

Upper Right: Trying out bamboo mold
Middle Right, Left: Using an electric earth compressor
Middle Righ, Rightt: Testing out water bottle thermal barrier

右上：测试竹片模板
右中，左：使用电动夯土机
右中，右：测试塑料瓶保温层

TRIAL RESULTS 试验结果

Here's the result of the trial build:
1) Time: The trial build, even though it was a very small structure, took much longer than we anticipated. We realized rammed earth construction is a very labor-intensive process that involves many steps. As a result we decided to combine the designs of the proposed walls into just one wall.
2) Thermal Barrier: The plastic bottle thermal barrier was not as effective as we hoped. We didn't realize when earth is compressed it exerts great force on everything around it, including the plastic bottles and the mold. The plastic bottles were not rigid enough to hold up against the compressive force and air was basically squeezed out, making the thermal barrier ineffective. We decided to abandon this idea and switched to using bamboo as a thermal barrier because it is a more rigid but hollow material with air cavity inside.
3) Bamboo Mold: The bamboo mold worked well and we would implement it in the final construction.

试验结果：
1）时间：试验结构虽然很小，但建造过程比我们预期长很多。我们发现夯土建筑是一个非常需要人力和时间的建造方式。基于这个发现我们也对最终的设计作出调整。由原来的两道墙减为一道墙，并且把它们的设计合二为一。

2）保温层：塑料瓶保温层并没有如我们期待那么有效。我们发现，土料被压缩的同时也会对四周的物料产生压力，包括塑料瓶和模板。由于塑料瓶比较软，很容易就给土料压扁，失去了原有的形状和里面的空气，让保温层基本上失去功效。我们因此调整设计，以竹筒代替塑料瓶，因它结构更硬，能够保持保温所需的空气层。

3）竹片模板：竹片模板效果很好，我们决定会继续使用。

MIX RECIPE 土料配方

We also tested different mixes of earth and other ingredients that would result in strong structural integrity and good water-resistance.

These are the ingredients we used:
1) Earth: We used red earth, which is wildly available in the Yunnan Province. It's red tone comes from the rich aluminum and iron oxides in the soil. We filtered the earth so that only particles under 1 cubic cm were used. This improved the adhesion between earth particles significantly.
2) Aggregate: We used typical rock/sand combination and avoided any aggregate that were too large.
3) Cement: Cement was used to make the mix more water-resistant. The amount needed to be carefully controlled as too much cement will affect material adhesion while too little will make the structure prone to water damage.
4) Fiber: Artificial fibers were added in the mix to improve overall material adhesion and sheer-resistance.
5) Water: Water content needed to be carefully controlled. Too much water will result in cracking of the structure, and too little water will result in poor material adhesion.
6) Dye: Non-structural, for aesthetic looks.

我们也根据物料的结构强度和防水性测试了不同的土料配方。
我们所使用的材料：
1）土料：我们使用了在云南地区很容易找到的红土。红土的颜色来自它里面的铝氧和铁氧矿物。筛土过程确保我们所使用的土里是在一立方厘米里。这样土料之间结合更好。
2）骨料：我们使用沙和小石子作为骨料。
3）水泥：水泥能增加结构的防水性。但水泥的份量必须小心控制。太多水泥会导致土料粘合度不足，太少水泥会导致结构防水性能太低。
4）纤维：使用人造纤维来增加土料的粘合度和抗剪力能力。
5）水：水份必须小心控制。太多水会导致结构开裂，太少水会导致土料粘合度不足。
6）色粉：非结构性，纯粹外观性，改变土料颜色。

MIX RECIPE 土料配方

	实量: Quantity:	步骤: Steps:	效果: Result:	评价: Remark:
配方一)	2 桶土，1 桶沙， 适量水 注：无水泥，纤 维，颜料	1) 把所以材料放进搅拌机 2) 开始搅拌，同时加水	1) 土料粘合度良好 2) 土料缺乏防水性	1) 土料没有防水性，下雨 很容易破坏结构
Mix 1)	2 buckets of earth, 1 bucket of aggregate Add water as needed *No cement, fiber, dye	1) Put all ingredients in mixer 2) Start mixing, add water	1) Mix has good adhesion 2) Mix is not water resistant	1) Mix can be easily damaged by rain water w/o water resistance
配方二)	5桶土，5桶沙 （3桶粗沙，2桶幼沙 ） 250g纤维，4.6kg水泥	1) 放沙和纤维，搅拌一分钟 2) 放一半水泥，搅拌一分钟 3) 放2桶土，搅拌两分钟 4) 放剩下水泥，搅拌一分钟 5) 加水	1) 搅拌不均匀 2) 材料太多，吸水不均匀 3) 水泥太多，颜色黯淡 4) 石子太多	1) 注意每一次搅拌的份量 2) 水泥不能太多
Mix 2)	5 buckets of earth 5 buckets of aggregate (3 course, 2 fine) 250g fiber, 4.6kg cement	1) Put aggr. and fiber, mix 1 min. 2) Put half of cement, mix 1 min. 3) Put 2 buckets of earth, mix 2 mins. 4) Put rest of cement, mix 1 min. 5) Add water	1) Mix is not even 2) Too much material, hard to evenly absorb water 3) Too much concrete, mix looks dull 4) Too much rock	1) Pay attention to water content 2) Reduce cement

FINAL RECIPE **最终配方**

配方三)	4 桶土，2 桶沙，1kg 水泥 2 把纤维（手抓的）， 根据温度适量增减水量 注：若要配有颜色， 量 为 8kg-10kg	1) 把所以材料放进搅拌机 2) 开始搅拌，同时加水 3) 如加颜色， 分次用撒的 4) 按情况加水	1) 土料粘合度良好 2) 土料防水功能良好 3) 土料颜色变化多	1) 筛土帮助大 2) 注意水量 3) 水量按室外温度调整
Mix 3)	4 buckets of earth 2 buckets of aggregate 1kg cement 2 bundles of fiber Dye, 8kg - 10kg	1) Put all structural ingredients in mixer 2) Start mixing, add water as needed 3) If add dye, spread powder evenly 4) Add water as needed	1) Mix has good adhesion 2) Mix has good water resistance 3) Many color options available	1) Filtered earth helped 2) Aware of water content 3) Adjust water content as needed because of outdoor temp.

PROCESS 建造过程

PROCESS 建造过程

PROCESS 建造过程

PROCESS 建造过程

FINAL RESULT 最后成果


BAMBOO THERMAL WALL
竹筒保温墙
BUILT-IN PLANTATION
一体式花槽
SEAT FROM BAMBOO MOLD
竹片模板座椅

EVALUATION 评估

1) Earth Mix/Recipe: One of the trickiest parts of rammed earth architecture is to get the mix right. Our biggest challenge throughout the construction process was the earth mix consistency. Sometimes the mix would be too dry, and sometimes it would be too wet because there are a lot of factors that could influence the humidity of the mix, e.g. outdoor temperature & humidity, lack of shading for the mixed earth, how soon the earth mix was used once it was made... etc. All these variables made different batches of mixes different from each other. As a result, one can clearly see discrepancies between each section of ramming. When too dry the wall would fall apart after ramming, and when too wet the wall would crack as water in the soil vaporized. Also, overly wet mix led to build up of material at the head of the earth compressor, making it less effective. Also, wet earth stuck to the mold easily, making mold releasing difficult.

2) Thermal Barrier: The bamboo thermal barrier held up quite well under constant ramming. However, since bamboo and earth have different thermal qualities, we say some cracks developed around the bamboo thermal area due to stress from expansion and shrinkage.

3) Bamboo Mold: The bamboo mold worked very well and created a constrasting pattern on the surface of the wall. It held up quite well under constant ramming. It was upcycled to become a seating surface of the wall.

4) Built-in Plantation: The plantation was successfully sucured inside the wall during the ramming process. Even with reinforced joints, the plantation form still deformed a bit. This showed form work in rammed earth architecture needs to be very strong to reduce warping.

5) Alloy Formwork: The alloy formwork worked for the most part. We realized that without the cross-brace even the alloy formwork could deform too. Also, since we did not apply demolding agent on the formwork, we saw some mold-sticking happening when we release the formwork.

6) Tool Wear & Tear: We broke 4 of the earth compressor's head. This showed that the tool design/manufacturing needed to be improved.

1）土料 / 配方：夯土建筑其中一个最有难度的事情是要找出最适合的配方。我们最大的挑战是于整个建造过程中维持土料的一致性。由于有很多因素可以影响土料湿度的缘故，土料有时过干，又是过湿。例如：室外温度和湿度，缺乏为土料遮阴，土料拌好后不一定立即使用等。这多个因素导致不同批次的土料都各不一样，夯出来的墙的不同部分也自然会有差距。当土料太干时土料夯不起来，土质松散。当土料太湿时土墙会因水份过度挥发而产生裂痕。过湿的土料也会导致土料粘在夯土机的头，降低夯土机的功效。最后，过湿的土料也会导致土料粘在模板上，从而令拆模变的困难。

2）保温层：竹筒保温层保持了它的形状，并没有如塑料瓶一样变形。但由于竹筒和土料的热胀冷缩属性不一样，竹筒附近的土料产生了裂缝。

3）竹片模板：竹片模板效果很好，做出了有意思的纹理。它的耐用性也很强，我们甚至把模板循环再用，拿他作为椅子。

4）一体化花槽：我们成功把花槽安装到土墙里。但由于夯土期间花槽的模板收到极大的压力，在已经有加固结构的情况下花槽结构还是有一点变形。这个也证明使用夯土技术时模板必须很坚固，以防受压变形。

5）铝合金模板：铝合金模板于大部分情况下操作正常。但我们发现纵使它强度很高，若没有用拉筋的话模板还是有机会变形。还有，因为我们没有用脱模剂，土墙在脱模时发生土料粘到模板上的情况。

6）工具磨损问题：四个夯土机的头于建造这道墙的过程中断了。这证明工具的设计和建造需要改良。

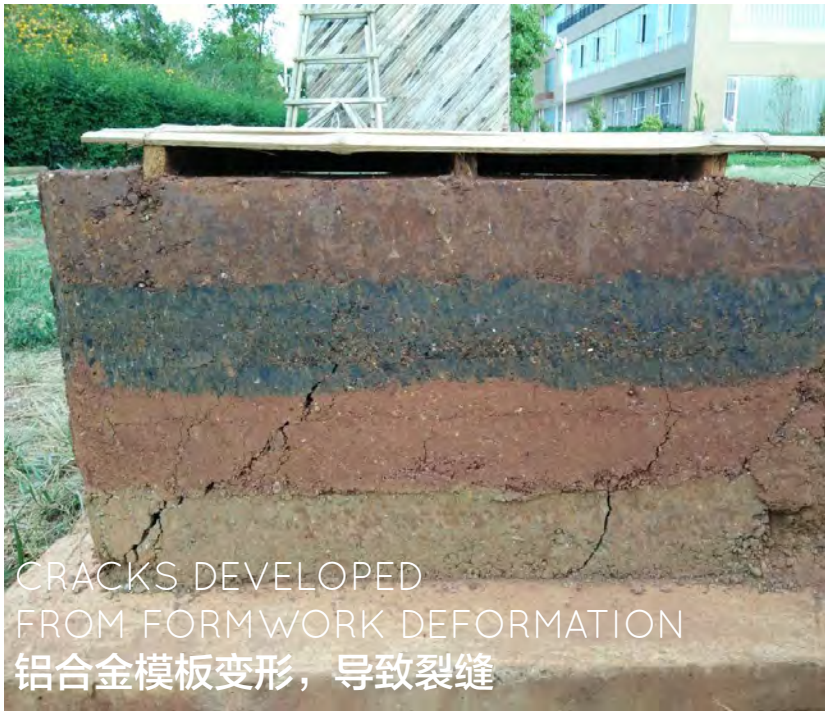

(BEFORE FIXING)
(修补前)
DEMOLDING PROBLEM
拆模板时粘土


(BEFORE FIXING)
(修补前)
INCONSISTENCY OF EARTH MIX
土料配方不一致


NOTICE THE FIBER
留意土料里的纤维
CRACKS AT
BAMBOO THERMAL BARRIER
竹筒保温层附近的裂缝


(BEFORE FIXING)
(修补前)
DEMOLDING PROBLEM
拆模板时粘土


TOOL WEAR
PROBLEMS
工具磨损问题


CRACKS DEVELOPED
FROM FORMWORK DEFORMATION
铝合金模板变形，导致裂缝

CONCLUSION 总结

In conclusion, the participants (most of them 2nd year students) did a great job from the beginning of this workshop to the end. They showed such passion in architecture and motivation to do their best, even though they have very limited experience and resources. Here are some of my observations from the workshop which I think were important:

1) Teamwork: In order to complete such a labor intensive project - from design to experiments to construction - in just under one week, and with a team that consisted of 8 members, everybody needed to have a very specific role in all stages of the project in order for the team to operate efficiently. A team leader was therefore selected early-on, and specific roles were given to each of the team members for both the design and construction stage. We also tried to be as effective as possible in our team structure: one example is that the student given the role to research construction method during the design stage was also responsible to direct the construction of the project. On the other hand, since this is an experimental project, each student were given a chance to experience different parts of the construction process (such as ramming the earth, mixing the earth, etc). But for most of the time people have dedicated roles so that they would become more effective as they gained experience.

2) Flexibility: The unexpected to be expected. Even though we had a pretty well thoughtout design, we realized that some of our ideas would not work too well in real life. This is where our trial built really helped. By doing a quick experienment we were able to make immediate adjustments to our final design. If we were too caught up with our original design we would not have completed the project on time.

总结来说，参与者（大部分是大二学生）从头到尾都表现很好。虽然他们的经验与资源不多，但他们对建筑设计充满热情，并且全力以赴去做得最好。以下是我对这个工作营的一些观察和觉得重要的事情：

1）团队合作：为了在不到一周的时间里完成一个非常耗时耗力的项目（包括设计，试验，建造），还有夯土组的人数有八个人之多，为了让团队能够有高效率，所有人都必须有明确的职责和位置。因此，在项目一开始时我们已经选好一个组长，而个人也有各自于设计过程和建造时的职责。我们也尽量维持团队架构的效率性，例如：在设计过程中负责研究建造方式的同学也是在建造过程里负责监督工程的工作。另外，由于这次是一个试验性的项目，每个组员也有机会去试试不同的建造过程（例如夯土，混土等）。但每个组员依然有各自的岗位，这样他们的效率也会随着经验的增加而提高。

2）灵活性：不能预计的事情总会发生。虽然我们有一个仔细的设计，但我们发现有一些想法实现起来真的不太可行。这个也是先做试验很有帮助的地方。透过简单和快速的试验所得的经验我们能够立即修改原来的设计。如果我们不愿意灵活变通的话我们有很大机会完成不了这个设计。

CONCLUSION 总结

3) Stay Calm and Solve the Problem: Even with the knowledge and experience from doing a trial built, we still faced a lot of problems during the actual construction. What we learned was to stay calm and simply figure out ways to solve them. One example was that we had pretty serious demolding problems and our wall was damaged in the process. But after some thinking we developed a way to repair these damages.

4) Be Organized in Construction: This applies to both the people and the location. Already mentioned before, each team member has a clear role. But this was not enough. We realized without clear communication the construction would go into chaos. For example, if the team members responsible for creating the earth mix was not informed of how much earth was needed, they could have mixed a lot more earth than what was needed, the surplus could potentially dry out before it was being used. On the other hand, if the earth-ramming people did not inform the earth-mixers of the need to adjust the water content of the mix, the earth-mixers might continue to make mixes that were too dry or too wet. Also, we saw a great need to keep the construction site organized. We could be using a dozen tools at the same time, and if these tools and parts were not placed or stored correctly, we would risk wasting time simply looking for something, effectively bringing the construction to a halt.

5) Documentation: Document every stage of the project. Documentation allowed us to go back and examine what went wrong and what could have done better. Without the massive amount of photos we have taken this report would not be possible.

3）保持冷静然后去解决问题：虽然我们已经从一些试验得到若干的知识和经验，但我们依然在实际建造时碰到很多问题。我们学会的是要保持冷静然后找办法去解决问题。其中一个例子是我们在建造过程中出现了脱模时土墙损坏的问题。我们其后找到补救的方法，成功把土墙修补好。

4）有组织性的建造：这个能够应用在人和地点上。刚才已经提过，每一个组员都有一个明确的岗位，但这个并不足够。我们发现若建造过程中没有良好的沟通的话整个过程会进入混乱的状态。例如，如果拌土的的组员没有被告诉需要拌多少土的话，他们可能会拌太多土。多出来的土也可能需要等一段时间才会被用，在这个过程里土料会损失水份，土料也因此失去原有的强度。另外，如果夯土的组员没有告诉拌土组需要调整土料里的水量，拌土组可能会持续拌出过干或者过湿的涂料，影响土墙的最终强度。我们也看到保持工地整洁的重要性。在建造的过程里我们同时使用很多的工具。如果这些工具和模板的零件没有被小心存放的话，我们可能会浪费很多时间寻找东西，甚至导致建造停工。

5）记录：记录整个项目的每一步。留了记录我们就可以在发生问题时查记录看看发生了什么问题和改善建造方式。没有我们庞大的照片记录这个报告也不能实现。

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