Revealing the Potential of Compressed Earth Blocks
A Visual Narration

by

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Submitted to the Department of Architecture
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Architecture Studies

at the

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Acknowledgments

Working on this thesis was a joyful and successful venture which could have been never realized without a group of generous and kind people. They all have been extremely supportive and influential, and I want to acknowledge their efforts in helping me complete this work.

My small family in Egypt: my father Kamal, my mother Ebtisam, and my brother Tarek. They have warmly and unconditionally supported me under all circumstances: most exceptionally, when I decided to postpone my education at MIT to stay in India for a year—a decision that, at the time, did not look very practical. They also continued their moral support while I wrote this thesis, which would not have been completed without them.

My advisors, John de Monchaux and John Fernandez, and my reader, Yung Ho Chang, have given me confidence with their unlimited support for my work in India. They proved to be the most open minded in their encouragement to venture an original medium for this thesis—a story board. It was a challenge, but through our meetings, the vague and untested idea gradually became clear and convincing. Thanks to them, the medium is as provocative as the project itself.

A few MIT students generously helped me as well. Some of the ideas in this thesis were crystallized during discussions with my friend Tamer el-Khouly. Tamer, a Physics PhD student, patiently listened to my ideas and asked intelligent questions, through which I better understood my work. My ever-helpful friend, Gena Peditto, revised the document linguistically. Her comments also extended to graphic design and storytelling, and Gena's meticulous corrections helped make the document more professional. My sophomore friend, Anna Kotova, who showed a passionate interest for the subject, helped me make this thesis a friendly read for undergraduate students. Anna's smart and sensitive comments had a very interesting impact on my work.

I have a special thanks to the de Monchaux's, whom I consider to be my family in the states. My friend, Nickolas de Monchaux, and my teacher, John de Monchaux, made me feel safe since I came to the States. They also have been the most influential to my work for this thesis with their very innovative and reflective ideas. John with his dedication, wisdom, and kindness has shown me a very rare and remarkable example that I believe will have a fundamental impact on my life.

Finally, I want to thank all of the craftsmen/women who worked with me on this project. They were a source of inspiration to me.

REVEALING THE POTENTIAL OF COMPRESSED EARTH BLOCKS

A VISUAL NARRATION

by

OMAR RABIE

Submitted to the Department of Architecture
on January, 18, 2008 in partial fulfillment of the
requirements for the Degree of Master of Science in
Architecture Studies

ABSTRACT

Compressed Earth Blocks (CEB) is a developed earth technology, in which unbaked brick is produced by compressing raw soil using manual, hydraulic, or mechanical compressing machines. Revealing the potential of an affordable sustainable material like CEB may help tackle today's fundamental challenges, social equity and environmental sustainability.

For one year in India, I learned and practiced the basics of this technology in Auroville Earth Institute, and then conducted a group of design and construction experimentations for a natural resort project. Through these experimentations, I tried to reveal CEBs' capabilities through design innovation. The thesis captures my new understandings of the design competence of the material in relation to the design process, through narrating the story of this experience using images and a dialogue between the designer, mason, sponsor and the blocks themselves.

Thesis Supervisor: John de Monchaux

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Introduction

About this thesis

I became interested in earth materials—specifically Compressed Earth Blocks (CEB)—while I working on my graduate degree in Architecture Studies at the Massachusetts Institute of Technology (MIT). During my second semester, I won an Aga Khan Program in Islamic Architecture (AKPIA) travel grant to take an intensive one month course at the Auroville Earth Institute in Tamil Nadu, Southern India, to learn about the design, production, and construction of CEB. One month became one year. For the first six months, I stayed in Auroville, then I left Tamil Nadu to work on a project for client in Madhya Pradesh. My education in the development of this project was both technical and social. I had the chance to practice what I learned at the Earth Institute, and then try to push the envelop of this technology with many experiments.I also managed and developed positive working relationships with fifty farmers, who were essential to the successful realization of my CEB experiments.

This thesis is not a pure technical manual about CEB. The reader can find dozens of these manuals, and many of them are noted in the biography of this thesis. Instead, this thesis details the path I have taken in pursuing innovation through a group of experiments. Thus, this thesis is complementary to traditional manuals. While the manual shows the reader how to successfully produce familiar forms of blocks, bonds, and buildings, the story shows the path that the author has taken to use this material in an untraditional way.

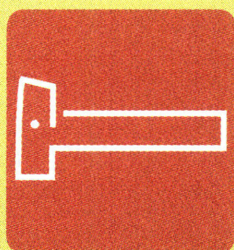
The reader will find that this story connects design, technique, and social issues because I found that they are, quite simply, inseparable. If, for example, an architect wants to go to a country area in a developing country to build a village using earth technology, it will not be sufficient to know only construction techniques. The architect, in such a case, will probably face much social sensitivity that has to be dealt with in wisely and delicately. This story communicates what I learned about navigating these situations.

The main audience for this thesis are young architects and architecture students who are in search of their paths in the world of design. Through this colorful and illustrated story, I hope to show them the excitement of this unusual experience in working on site with earth. Since I took the role of the advocate of this material, I am trying through this medium to convince others to share my purpose.

Introduction

Story Board

Characters

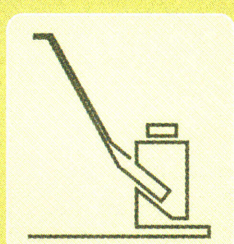


architect

The Architect

He is an Egyptian architect and a Master of Science in Architecture Studies student at the Massachusetts Institute of Technology (MIT). He won a grant from MIT to travel to learn and practice Compressed Earth Block (CEB) technology in Auroville Earth Institute, India. While at the Earth Institute, he met with an Indian architect who asked him to be his partner to design and build a natural resort in Madhya Pradesh, India.

After practicing CEB technology in Auroville Earth Institute for half of a year, he saw this project as a good chance to experiment with the material, to develop the technology, and reveal its potential.



production team

The Compressed Earth Blocks (CEB) Production Team

They are a group of around fifty farmers (men, women, girls, and boys) from a small village, Beroleh in Madhya Pradesh, India. Most of their homes in the village are built with either mud brick or fired brick, which they produce in the village. CEB technology is new to them. Therefore, the architect had to give the team on-the-job training. They showed an eagerness to learn the new technology.

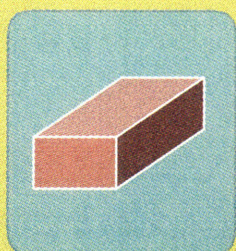
I like and admire those farmers. They are honest, hard workers, flexible, and eager to learn.

They came only to produce the CEB needed for the natural resort project. At some point, they started to consider using the technology for their own homes in the village.

Introduction

Story Board

Characters

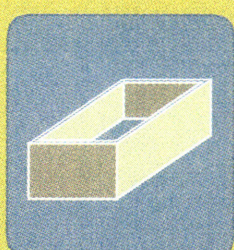


Block

The Compressed Earth Block (CEB)

CEB is considered a modern earth technology in which soil is compressed using manual, hydraulic, or mechanical compressing machines. Before the compressing machines, CEB was produced manually by tamping soil into molds made by wood or metal. In this story, the block is the CEB that the team has produced either by the compressing machine available on the site (Aurom 3000) or by the manual method we rejuvenated and developed for our experimental purposes.

Designing a building could start from designing a block.



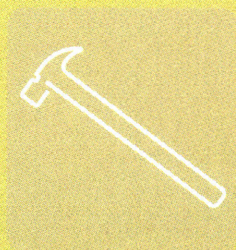
mold

The mold of CEB

When we think about the design of a CEB block, we have to think about the design of its mold. CEB molds are different from adobe or backed brick molds. Soil is rammed inside these molds. It should be every strong to handle compression. There should be an easy way to get the compressed block from inside the mold after it is compressed. In this story, the mold can be the metal mold used for the compressing machine, or the experimental wooden molds devised on the construction site.

Understanding the mold of CEB is the key to innovative CEB block design.

Characters

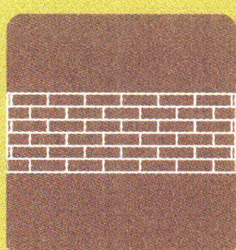


carpenter

The Carpenter

He is a young carpenter with one helper from Jabalpur (a city near the construction site). His main job was to work with the architect to develope experimental wooden forms and accessories (inserts) to be used for the production of CEB. He was not familiar with the production process of CEB, nor the properties of the forms needed to produce CEB. The experimental nature of the work added considerable difficulties to his work.

The architect himself was learning through trial and error with the carpenter. The carpenter and the architect had to work closely together through the whole process to develop the original methods.



mason

The Mason

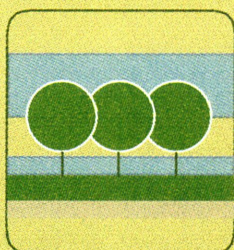
He is a mason from the village with thirty five years of experience, yet he has no experience with CEB. He works with mud bricks as well as the village fired bricks. In both cases, he never needed to build a wall with exposed brick. The design of the natural resort rooms uses exposed CEB with no render in many parts. Therefore, the architect tried hard to teach the mason to build a wall that has clean joints using exposed CEB.

Can the architect succeed in changing the thirty five years of habit?

Introduction

Story Board

Characters



site

The Site

The project's site is inside a protected natural resort zone. This natural resort area is famous for its variant plants and animals, especially its glamorous tigers. A river separates the site from the sublime natural forest, which naturally stands out as the main view of the rooms. The site's majesty demands a design that respects its characteristics and different phenomena (for example, trees, topography, monsoon, light and shadow).

The design of this natural resort should reflect a sensible dialogue between the site and materials.

client

The Client

The client is not one single person, rather "client" refers to the expected guests of the natural resort. Visitors, of all ages and professions, come from nearly all corners of the planetand for different reasons. For example, the client could be a European scientist studying an indigenous tree type, or an Asian photographer taking pictures of the tigers, or a young Indian group enjoying safari. So, it is very difficult to clearly

Since the client is unidentifiable, the design has to be able to speak to different clients on different levels. The key is variety. We may need different types of rooms.

architect partner

The Architect Partner

He is a young Indian architect who runs an architectural office in Jabalpur (a small city in Madhya Pradesh). Because of his deep interest in sustainable architecture, he spent a month at the Auroville Earth Institute to learn about CEB, where he met the architect. He did not participate directly in the design process, nor in the making of the mock-ups.

His main role was to facilitate the communication between the sponsor and the architect, and to assure the fluidity of the construction process.

sponsor

The Sponsor

He is an Indian investor. He owns land inside the natural resort zone. The architect partner convinced him to build the rooms in the natural resort with earth. He is open minded and willing to give the architect freedom to innovate. He is able to provide the architect with whatever is necessary to achieve the best results.

Talking to the architect: "You are the architect. You do your work. I want the best."

Introduction

Story Board

Place

Beginning
of
Story Board

At MIT

I will focus on building technology and materials. If I become an architect who is in control of the materials and the construction process, I can build efficient and beautiful buildings for the poor one day.

mit.edu

In Auroville

CEB is the technology I need to learn at Auroville Earth Institute. It is a sustainable earth technology but yet refined and developed. I have to learn to be a mason, so I can train builders wherever this technology is not popular. Finally, I am ready.

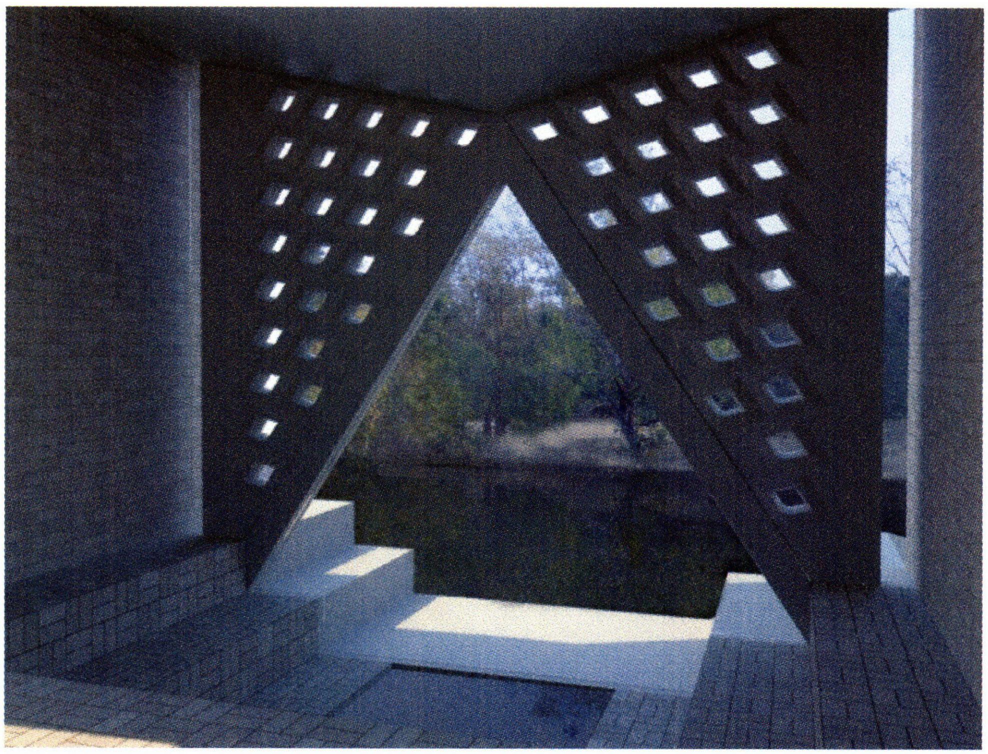
In Beroleh

Now I have the experience to use CEB. I have many ideas. This project gives me the chance to try to evolve the technology through experimentations. It seems like a very good chance, beautiful site, and open-minded sponsor.

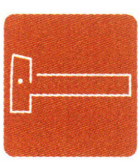
The River Wall

Story Board

Challenge



computer simulation by the author



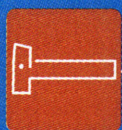
Challenging CEB:
The architect wanted to reveal the capabilities of CEB by challenging this material. He used the material in almost every part of the room: exposed structural walls, floors, and furniture. Here the architect used the standard blocks produced by the machine in most parts of the building: interlocking blocks for the structural walls, and tiles for the floor with its steps. Yet, there is a special wall that the architect thought may need special attention. This wall separates the space of the room from the overwhelmingly beautiful river and natural forest (the main view for all of the rooms). Therefore, the architect designed a special form of blocks that is usually not produced by the machine, and consequently needs a very special brick bond.

The River Wall

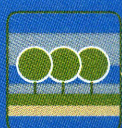
Story Board

Evolving Conversation

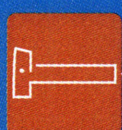
Dialogue



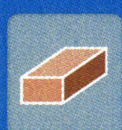
Can we challenge and then develop the capabilities of a material through design?



In the natural resort, nature should be the dominant force to influence design. Material should prove to be flexible enough to react to this force. Does this make sense?



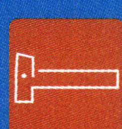
Yes, this does make sense to me.
Earth materials are usually perceived as heavy. Yet, this river wall should be light and semi-transparent; it separates the space of the room and the over-immense natural scene of the river and forest. This river wall is a gate to nature; it should be special.



Innovative unit (block) design and consequently block bonding can help the material to face this challenge beautifully.

Designing special block means designing special mold. To be able to design innovative forms of blocks, the architect has to understand the traditional production process of CEB first.

Will traditional masons available in the area of the construction site be familiar with the material (CEB)? Can they work with new forms of blocks and bonds?



If the answer is yes, then we are ready to build.
If the answer is no, then the architect should be able to teach the masons through a group of mockups.

The River Wall

Story Board

Dialogue

Evolving Conversation

$ — I want the room to look like a fish.

Showing a picture of a building that looks literaly like a fish.

(speachless)

Interesting, we will study this idea and see if it is good or not. We will also study other ideas and select the best.

$ — Yes, I want the best. You are the architect. I am just giving you an idea. You show me different good ideas.

Later…

Do you really want to build THE fish? :-)

NO, but I never say "NO" to a client.

Ok, step by step. We have to get him involved in the design process until we all get together to a common ground; eventually we also have to finish the design of the first room, make a photo realistic render. Then we can show him the picture and say the room will look exactly like this; do you like it?

The River Wall

Story Board

Dialogue

Evolving Conversation

Who is the client?

The sponsor is my client.

The sponsor wants a financially profitable natural resort. It is part of our mission to make this happen. To achieve that, we have to understand, that he is not the client that we have to talk to through our design.

???

Who is the client?
It is hard to identify the client in this case. During the season, they are mostly foreigners. Some scientists, photographers, university students, come to observe, study, and photograph nature, especially tigers. Some come just to relax and enjoy nature. Some Indian tourists come during holidays.

We cannot build this project if the sponsor is not happy.

Fair enough. We have to speak to many people on different levels. We need variety. There will be many rooms. While it will be practical to make the first room acceptable by our sponsor, so we can gain his trust to build the rest of the project. I would like to make the last room to speak to an artist for example. This gradual approach makes sense not just for the sponsor, but also for us, because we will get a lot more confident using the material (CEB) by the time.

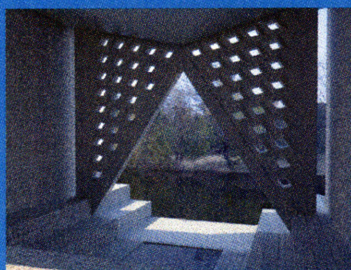
The taste of sponsor, the architects understanding of the material, the material capabilities, the craftsmen ability to deal with the material should all evolve together while working on the project. That will be a healthy process that can reveal the potential of such a material. it is almost impossible to push the envelop of such a technology without such a healthy process. These are inseparable.

The River Wall

Story Board

Evolving Conversation

Check



This is how the first room will look. You know the site and you know this view. We wanted the first room to look and feel somehow like a palace, to respond to this palatial view. The big triangular opening and the perforated blocks of the wall that look at the river, will assure maximum view. The perforated books will filter the light inside the room. I call this wall *the river wall*. The steps will be covered with some pillows and used for seating. The tub will be part of the room and positioned in the center of the room very close to the river. The room also has an open terrace with steps looking at the river.

$ So, there is no furniture. All will be made of earth blocks? The bed looks at this view? The room wil look like this?

Yes.

$ Ok, go and build this room.
If we find that the CEB is good and can do this, then we build the rest of natural resort with it.

I will go to the site to work on the production. At the same time I will make group of mock-ups (small walls off CEB), so you can see the material yourself before the construction starts.

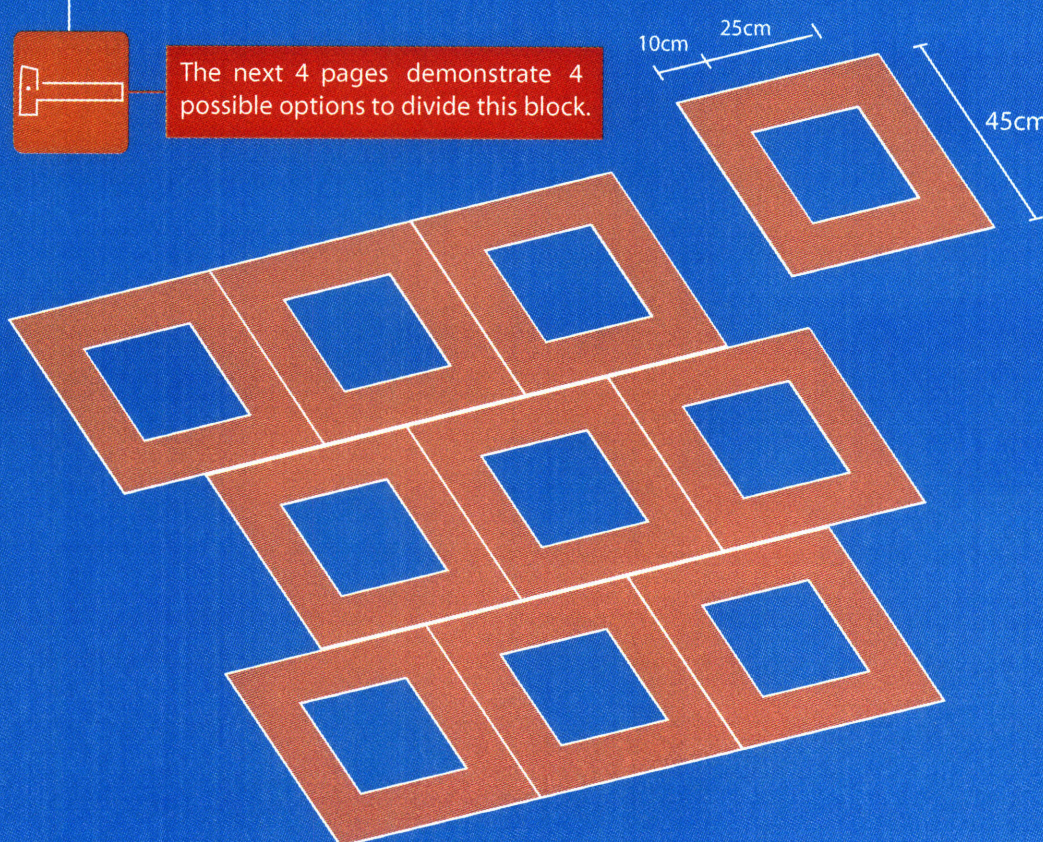
$ Good. I will come to see it. I am interested in the material, but I want to see it myself first in reality, not just on the computer.

Divide and Conquer

Producing the block suggested by the drawings prepared before going to the construction site, was very problematic. First, the scale of the block made it difficult to carry and handle. Second, because of its size, It was also very difficult to produce by manual compaction (in wooden molds), this is because bigger areas to compact have a greater chance compacting unevenly. Uneven compaction usually results in cracks while removing the mold, one of the reasons that make the compressing machine superior to manual compaction.

One way to produce the perforated parallelogram with the same proportions and avoid most of the difficulties mentioned is simply to divide the one block into two pieces. This method, which in this case, is applied in a very simple manner, can be the method to solve more complicated problems to achieve unusual results with masonry, and to find innovative bondings using blocks.

The next 4 pages demonstrate 4 possible options to divide this block.

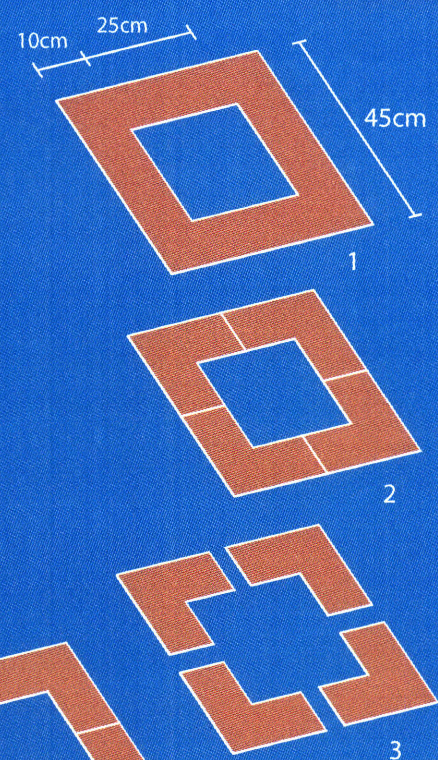


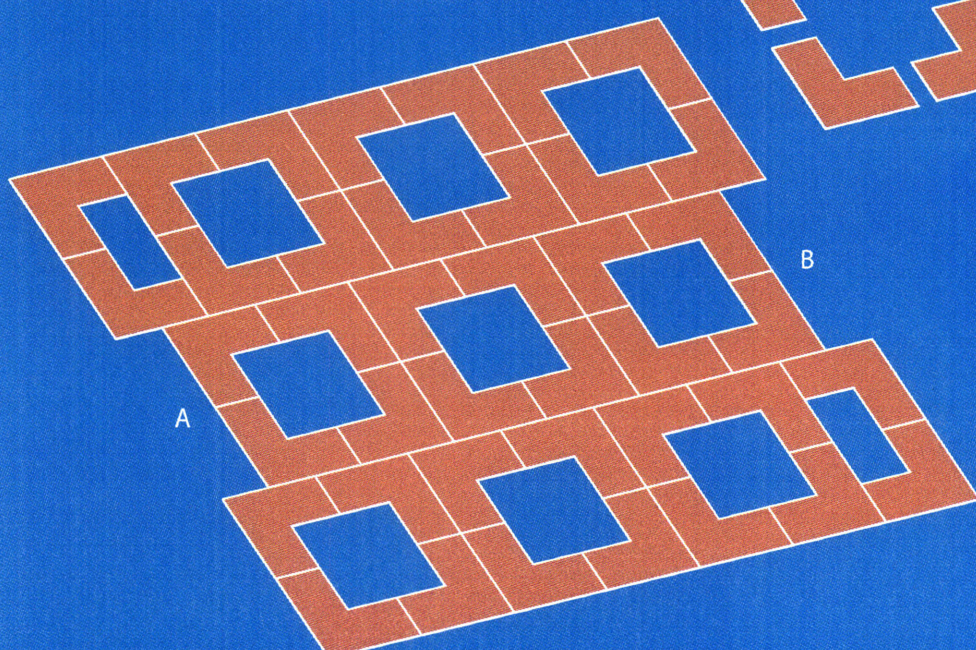
The River Wall

Divide and Conquer

The Block:
In this option, the block is divided into four similar parts, which means that only one mold will be needed to produce these blocks. Yet the complexity in this case comes from the form of every part. The "L" shape with its corners might impose some difficulties while making the mold as well as ramming, if manually produced. In this option, to cover-the two voids seen in the drawing below (A, B) with clean blocks (meaning with no cuts), we will need a new mold. Otherwise, the mason will need to cut the "L" shape block to have two pieces that will cover these areas.

The Bond:
The shift between the semi-vertical joints is enough to assure the strength of the bond.

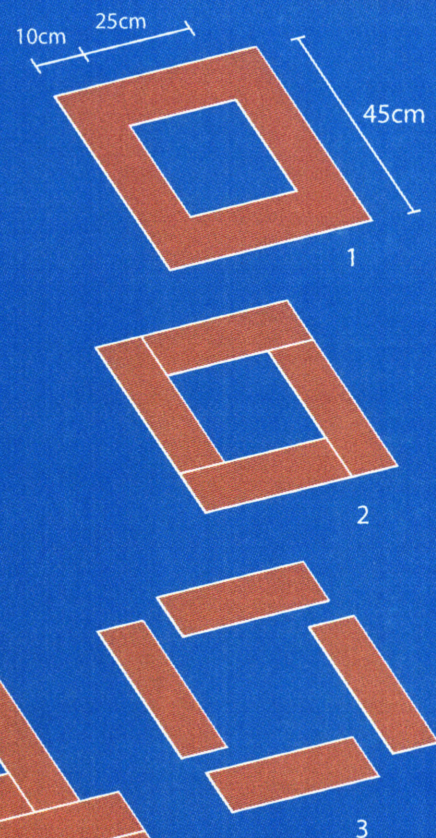


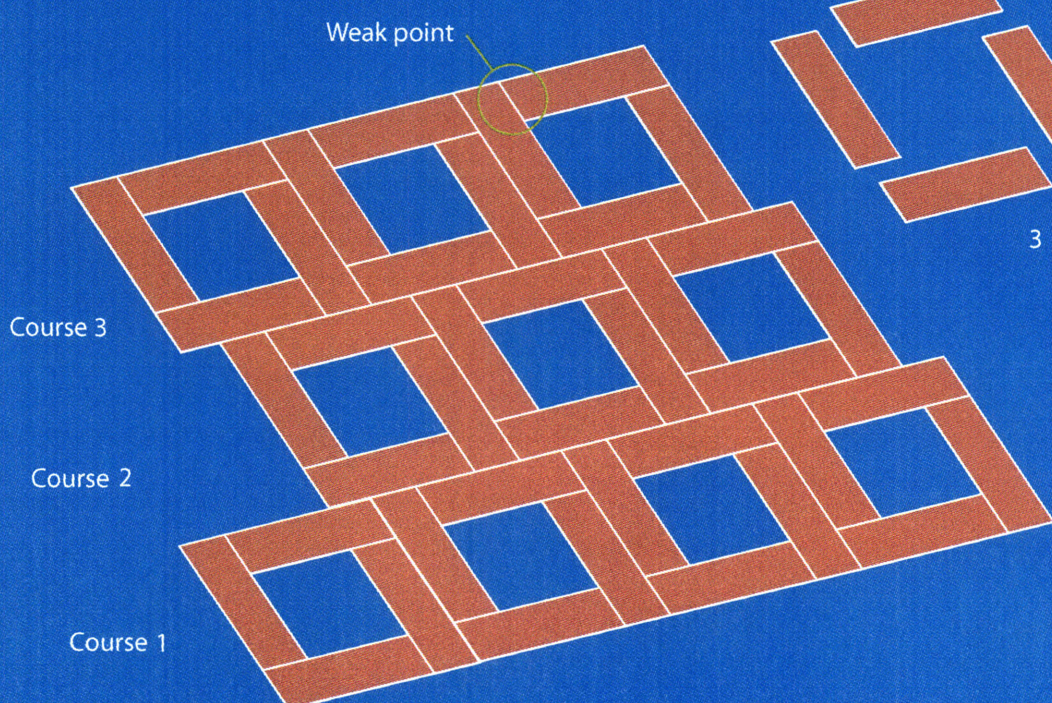


Divide and Conquer

The Block:
In this option, the perforated parallelogram is divided into four similar pieces. One mold will be needed to produce the blocks. The block is a parallelogram with proportions that would probably make the block easy to carry and handle.

The Bond:
This solution would impose some difficulties while finding the right bond for the wall. It would create weak points. To assure a sufficient shift between the semi-vertical joints, we might need a bond that consists of three different repeated courses instead of the ususal two repeated courses (odd and even).



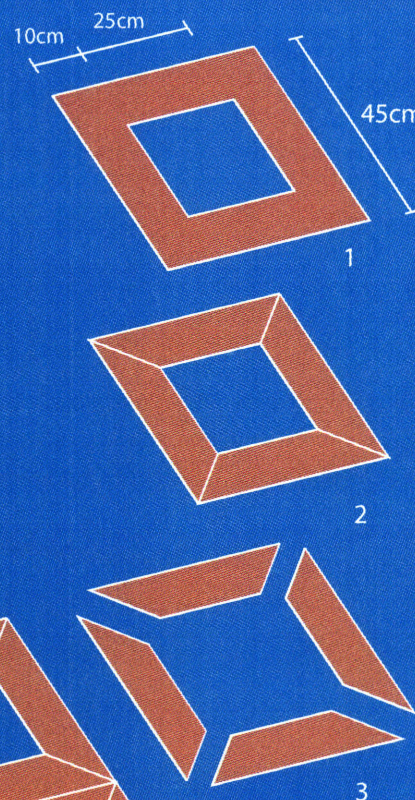


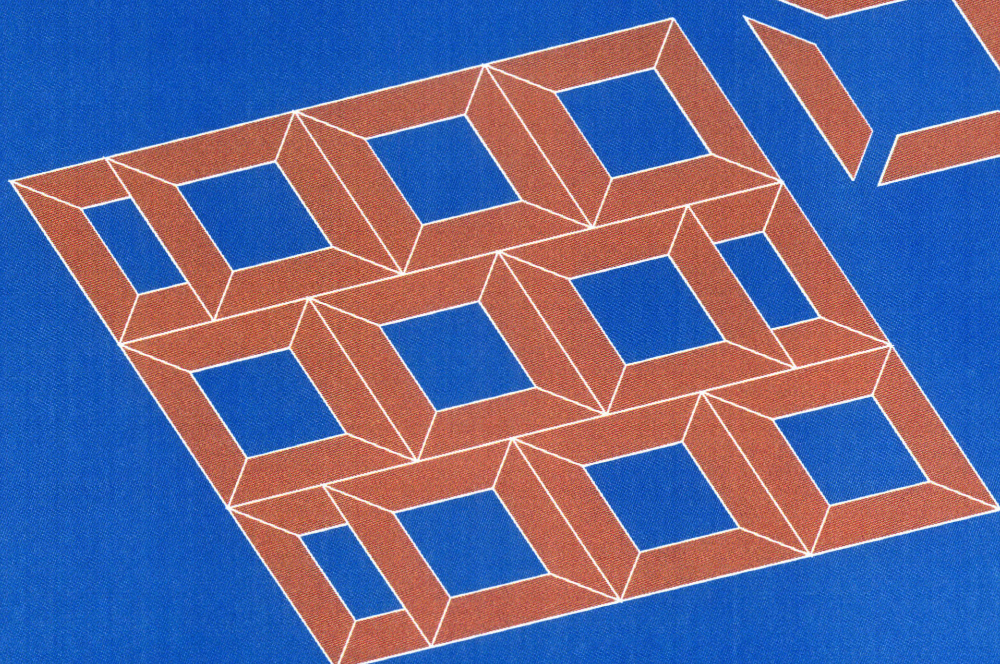
Divide and Conquer

Divide 3

The Block:
In this option, the perforated parallelogram is divided into four pieces with two different forms. Two molds will be needed to produce the blocks. The molds with its non right angle corners will be more difficult to make accurately onsite. The block corners with two acute angles will be relatively fragile and more difficult to handle.

The Bond:
This solution provides a very simple and strong bonding. The semi vertical bonds are sufficiently shifted from each other.





The River Wall

Story Board

Divide 4

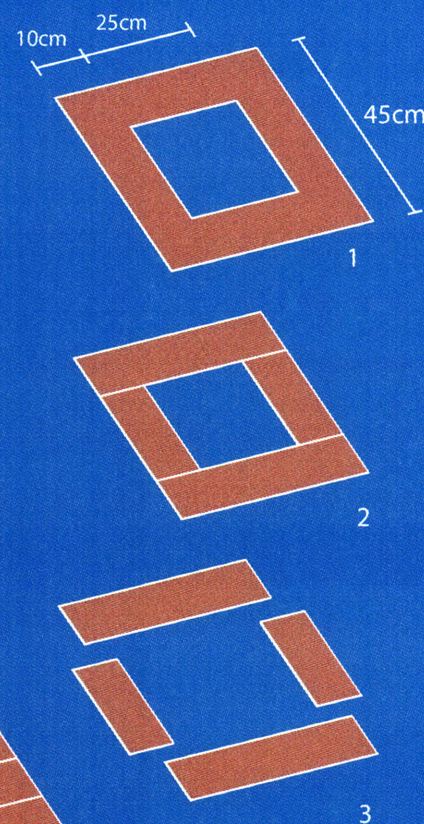
selected option

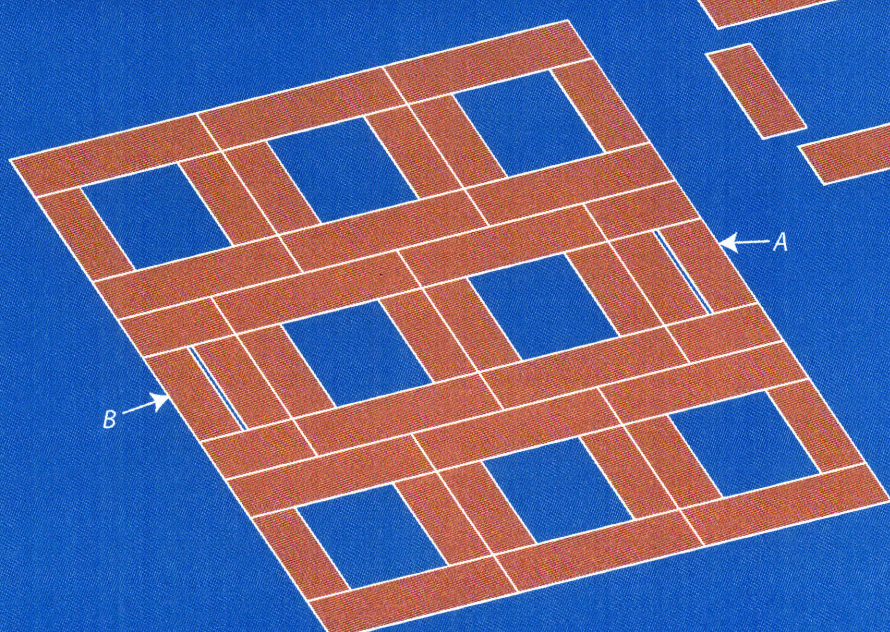
Divide and Conquer

The Blocks:
In this solution, the perforated parallelogram is divided into four pieces with two different forms: a longer parallelogram and a shorter one. Two different molds will be needed to produce the blocks. This solution offers some advantages. The two molds are simple and may be easy to make. The two forms of blocks should be easy to handle and lay.

The Bond:
The shift between the vertical joints is enough to assure the strength of the bond. The empty areas (A, B) created at the edges are easy to fill using two of the shorter parallelogram blocks.

This solution was selected for the mockup





The River Wall

Story Board

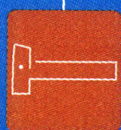
Divide and Conquer

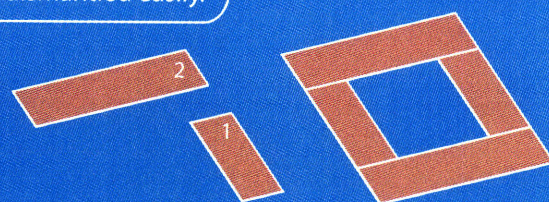
block production

Divide 4

selected option

To be able to produce the designed special units for the river wall with the same scale, the architect decided to divide every block into 4 pieces, with two forms. All have the same shape with the same angels, but the upper and the lower unites will be longer (2), and the two sides will be shorter (1). The difference is in the length. The team developed a very simple wooden mold that can be dismantled easily.





The River Wall

Story Board

Divide and Conquer

mock-up assembly

Process

1

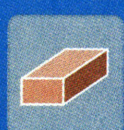
2

3

4

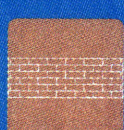
5

6



For this mock-up, blocks have two shapes. The block used for the top and base (form number 2) has a linear proportion, which had implications on the construction process. The design of the unit can fundamentally influence the construction process.

The manual blocks' production team had to participate in making this mock-up as the mason helpers. Two of them were needed especially to carry the long block from the storage area to the mock-up area.



The mason handled even the unusually long pieces with surprising ease. Yet he was not able to assemble the mock-up correctly by positioning the blocks on the right place without the architect's guidance.

The River Wall

Story Board

Divide and Conquer

mock-up assembly

Process

The architect guided the construction of this mock up step by step. The workers saw the drawings, prepared the molds, rammed the soil to produce blocks, and then started the assembly without asking any questions. Yet during the assembly, it was clear that not one of them could imagine how this wall would be assembled. Maybe the architect was not able to communicate and clarify his idea enough. The more the whole team is conscious about the process and the expected final product, the more we can reserve time and energy. All efforts should be done to find creative ways to get the whole team involved in the process and aware of the anticipated results.

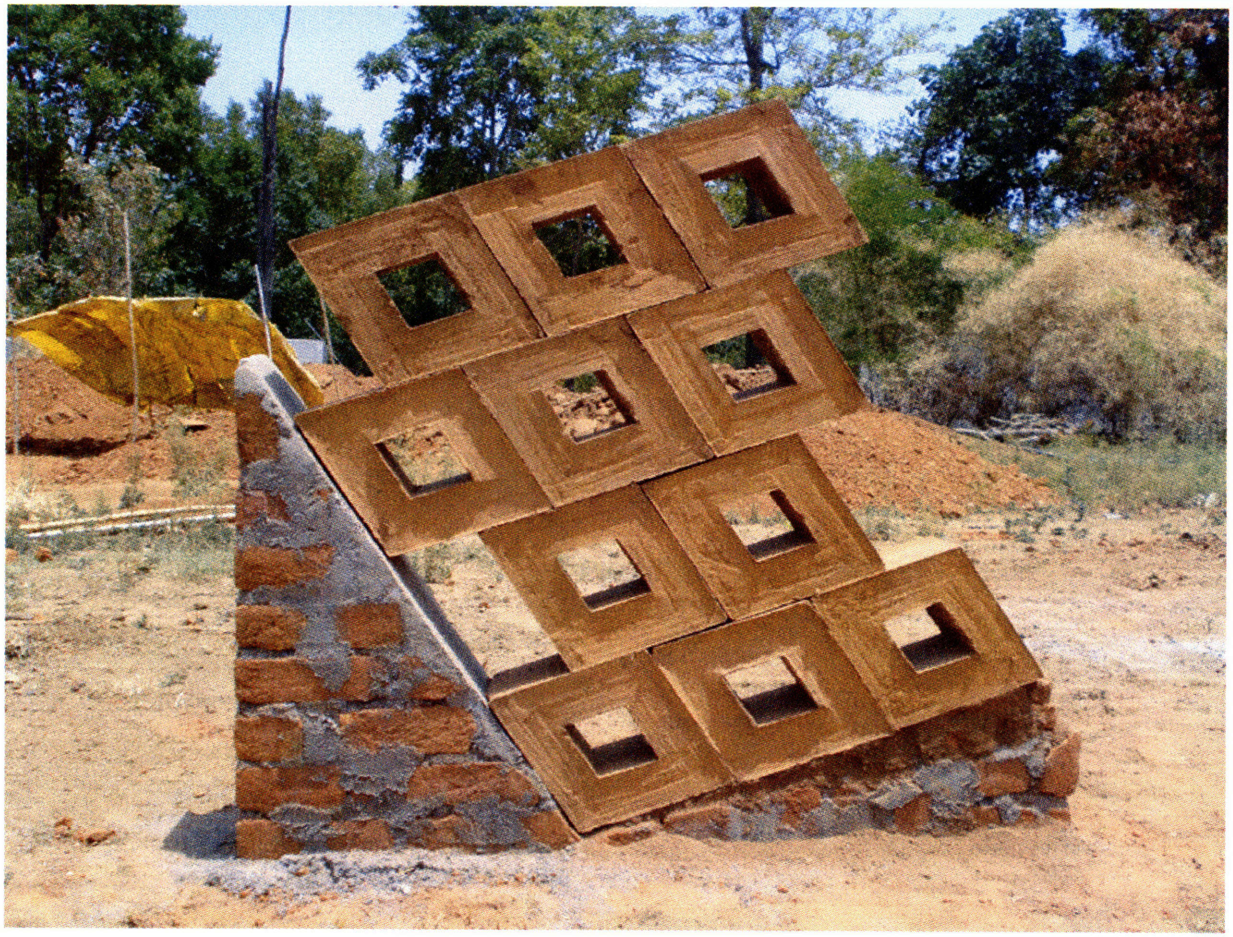
The River Wall

Story Board

One piece block

the final solution

Success!



The divide and conquer solution was sufficient, but it was not satisfying to the architect. He wanted to produce a one piece perforated parallelogram.

The main aim of making this group of mock-ups was to, first find the most efficient way to build this wall, and then to leave production team, the carpenters, and the masons with a clear construction process so that they could build such a wall.

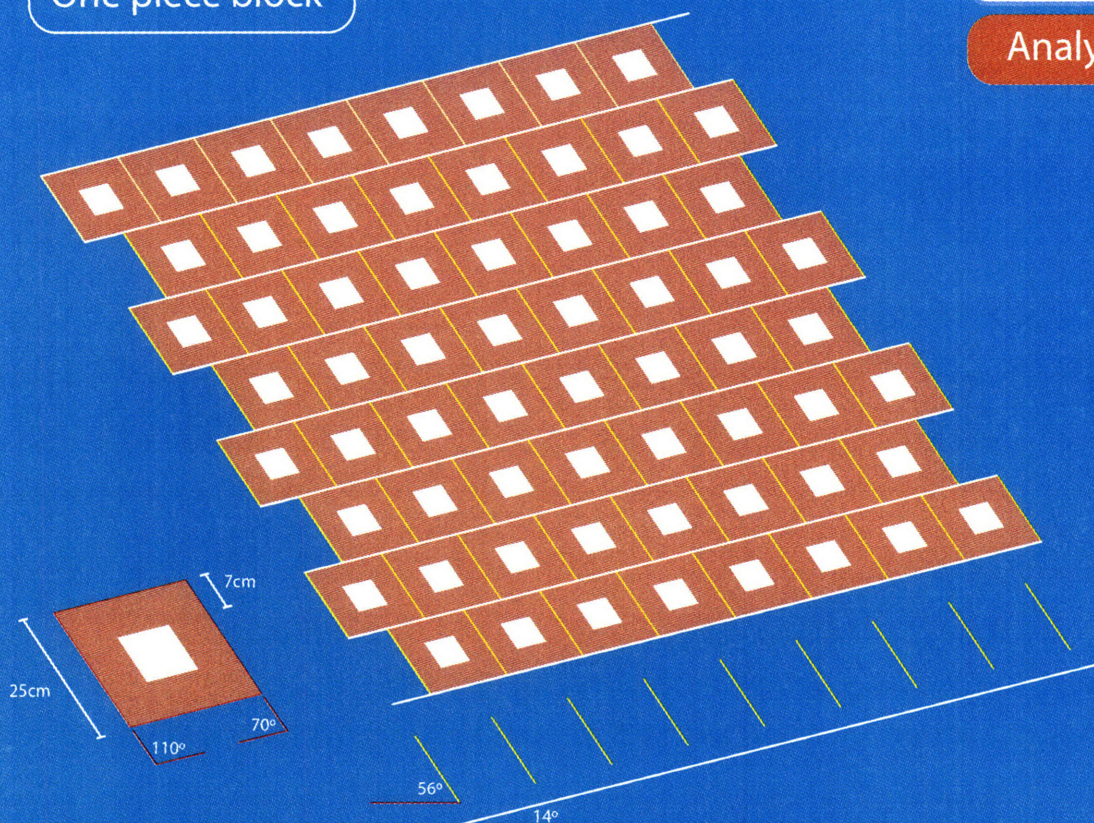
After many experimentations, the making of this mock-up was was the moment when the architect knew that the team was ready to start the construction of the first room in the natural resort. This was the moment of success

The River Wall - one piece

Story Board

Analysis

One piece block



The Block
The block is perforated, with 70 and 110 degree angels, which might add complexity to the production and construction process, only if the team did not master an easy and effective process to make this type of blocks and then to build with it.

The Bond
The brick bond here is very unusual, because the joints are not horizontal and vertical like all of the popular brick bonds. It might be an advantage to have no vertical joint (90º), because the wall might be stronger against shear force. Not having a horizontal joint might be the concern here, because the blocks might slide during construction.

The aim of this mock-up was to find an efficient process to produce this form of blocks and to make sure that we can build this wall with its unusual bond.

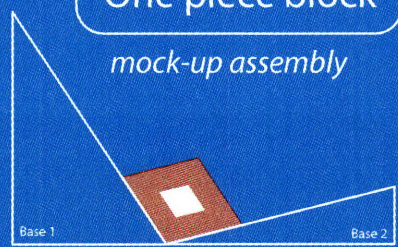
The River Wall

Story Board

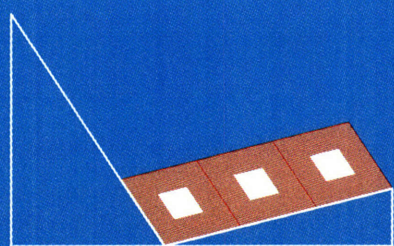
Process

One piece block

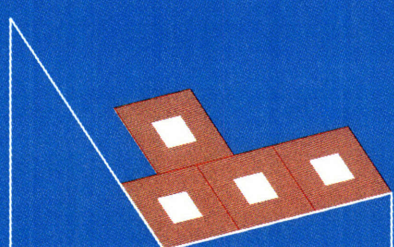
mock-up assembly



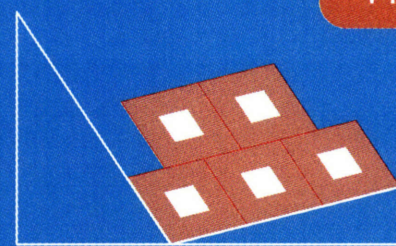
1) Making the two bases, and laying the first block



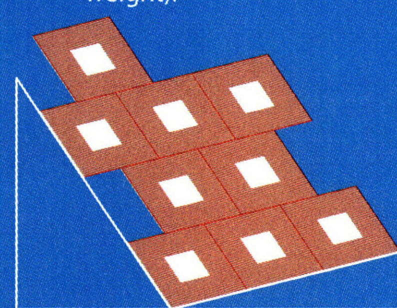
2) Laying the second and third blocks to finish the first odd layer.



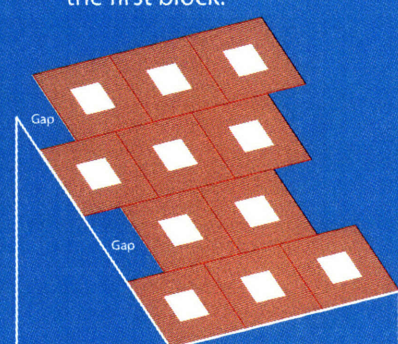
3) Laying the first block of the even layer is the single most important moment of this experiment. Will the block slide or not? The block did not slide and was very stable even without mortar.



4) Still did not slide despite adding another block (meaning adding weight).



5) Laying the second odd layer and the first block.



6) Still did not slide despite adding another two blocks this time (meaning adding more weight).

The wall will eventually be constructed using mortar. The gaps will be covered by blocks. So, the wall proved to withstand more difficult conditions than expected. This was enough proof that the wall with its unusual bond is constructable.

The River Wall

Story Board

Flash back

Eventually , the architect succeded in leading the team to meet the challenge that he proposed through design. Nevertheless, this success only came through persistence and after a period of trial and error.

During this period of trial and error, the carpenter started to look a little frustrated, because he already made different types of wooden molds, but non of them proved to be suitable for producing CEB. The production team was watching from a close distance and smiling. This mood of doubt might easily be transferred to the sponsor.

This unhealthy atmosphere can never lead to a successful process and successful final product. It was the time for the gentleman architect to question his priorities. The architect had expected that there would be a period of trial and error. To achieve the perforated parallelogram form (proposed using computational tools), he had revived a seventeenth century technique to manually produce CEB using wooden forms and manual rammers. Furthermore, it was not recorded that this technique was used before to produce blocks that has such a form. The complexity and originality of the adventure did not mean much to the workers or sponsor. For them, there are always two kinds of blocks-good and bad, strong and week, beautiful and ugly.

The architect started to feel that it might have been a mistake to go through these experimentations at the beginning of the process and in front of everybody. He decided to move to another experiment that he expected to succeed from the first time and may come with impressive results. Once he gains the trust of his team of workers and his sponsor, he can return to pursuing a solution-for this problematic river wall.

One Curve and Four Walls

Story Board

a curve

Speculation

What can we do with a single curve?

It has been almost three weeks of work on the construction site. Everyone have been continuously working together: the architect, engineer, carpenters, and production team. The amount of blocks produced during this period was almost enough for the first room of the natural resort. The speed of block production was not ideal but it was sufficient for the time being. Most importantly, an atmosphere of harmony and confidence started to emerge; it was the right time to gain the best of this healthy atmosphere.

From the very beginnng, I wanted to make a clear statement about the infinite possibilities that emerge once the designer decides to challenge the standardized units (blocks) that the compressing machines produce. I finally felt that I understood the capabilities and limitations of the material, the machine and the craftsmanship. Therefore, I clearly saw the possibility to make a clear statement with the least effort: a convincing, assuring statment for me, my partner, my client, as well as the architectural community.

Working with CEB, I had a very wide range of freedom to design the form of blocks I wanted, if I could make my own machine's molds and accessories. I thought that making a metal mold for the first trials would be too expensive of an effort for unguaranteed results. Yet, working with the carpenters, I could easily make new wooden mold accessories here, on site. To simplify the process more, I decided to produce my mold accessories using a single profile curve. At this point I vaguely saw units with undulated surfaces that could be used whether for the exterior or interior for different purposes, but it was not very clear to me in which part of my building exactly these units would be used. It was uncertain to me as well the type of blocks bonding I could use with this type of blocks. It was the first step towards a relatively unknowable destination.

One Curve and Four Walls

Story Board

Gestures

a curve

The architect had to communicate with the carpenter through gestures sometimes, because both of them speak different languages. To describe how the curve profile will shape wooden accessory, the architect moved his hands over the surface of the wooden log starting from the four corners to the center showing the carpenter how to carve it. The carpenter responded by moving his hands as well over the log; he was asking the architect whether he is visualizing the form accurately. A nod of agreement between the architect and the carpenter was the sign to start carving. Body language proved very effective through the whole process.

One Curve and Four Walls

Story Board

Insert

The carpenter automatically generated a plan on the wood log; both the curve profile and hand gestures indicated that the form is close to a dome. Therefore, it did make sense to the architect that the plan the carpenter generated was simply the plan of a dome, with the usual four triangular corners (*pendentives*), which transforms the rectangle into a circle. Then the carpenter started carving from these four corners.

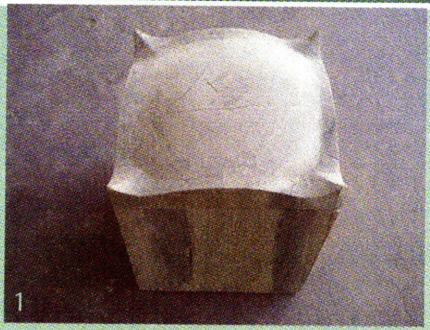
One Curve and Four Walls

Story Board

Trial

a curve

1) The wooden mold *insert* ready for the first trial. The carpenter carved the accessory and cut it out of the wooden log. Then he smoothed its surface to be ready to produce the first trial block.



1

2) The wooden mold insert positioned over the lower plate of the machine mold. There should be no soil in between the wooden insert and the lower plate. There should be a suitable tolerance of about 1mm between the edges of the wooden insert and the side plates of the metal mold.

2

3) If the tolerance is less than optimal, the vertical movement of the lower plate carrying the wooden mold will be difficult. If the tolerance is more than necessary, the soil will fall in between the wooden insert and the side plates while compressing.

3

4) The first block.
One easy way to test the block is to part the block from the mold and see whether it stands up on its side or whether it cracks, once it is compressed. The height of the block should also be measured, and the penetrometer should be used to see if the soil is suitably compacted.

4

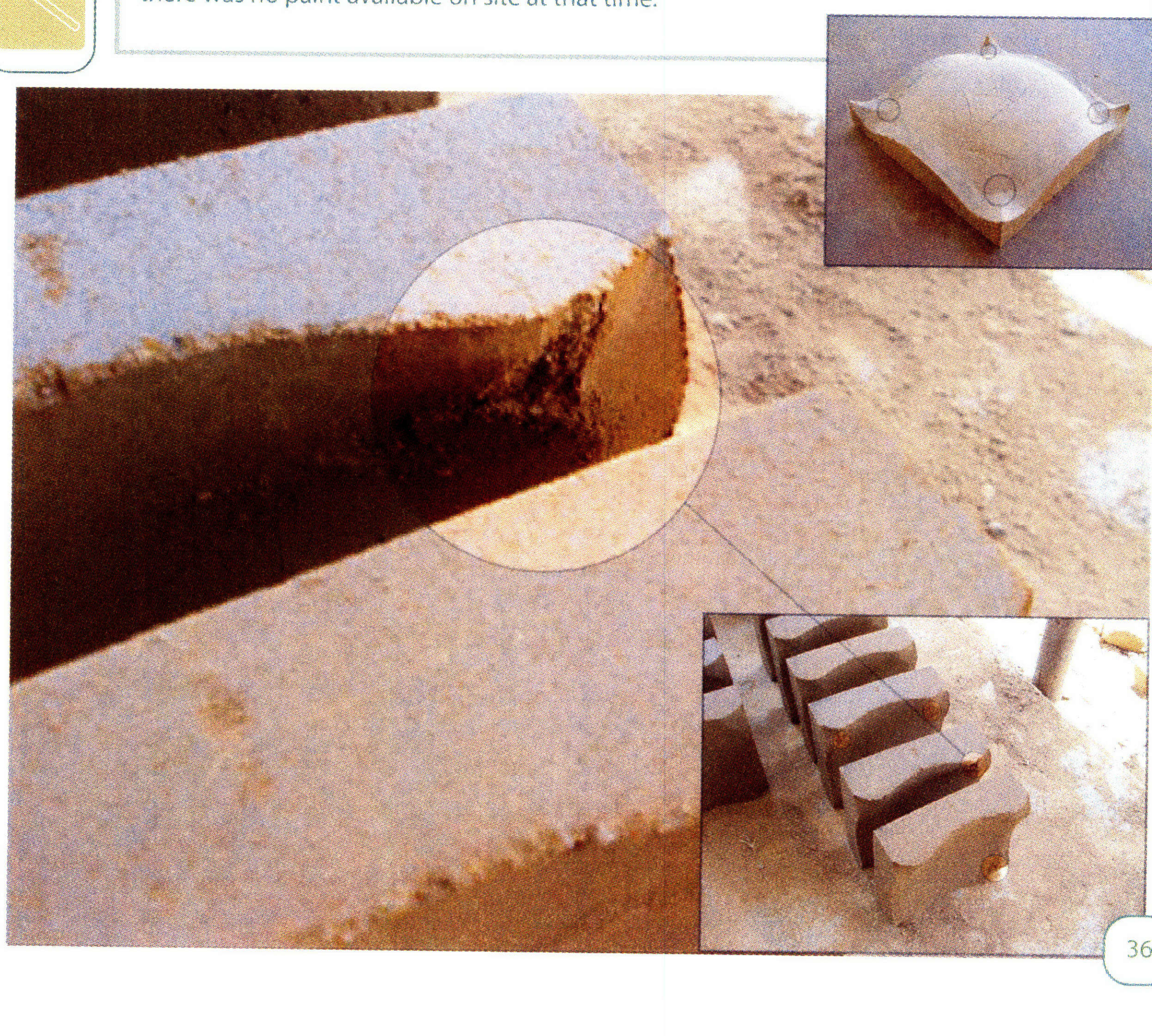
One Curve and Four Walls

Story Board

a curve

Problem

The architect, the carpenter and, and the machine workers were working together on producing the first blocks, jointly solving problems as they arose. They found that the moist soil sticks to specific spots (the four corner spots at the turning point of the two curves). To avoid that, they learned It was very important to keep the mold accessory smooth and clean. Eventually, they stopped production and the carpenter took the insert to smooth these four corner spots. A more ideal solution would be painting the surface of the mold as well, but there was no paint available on site at that time.



One Curve and Four Walls

Story Board

Mock-up1

a curve

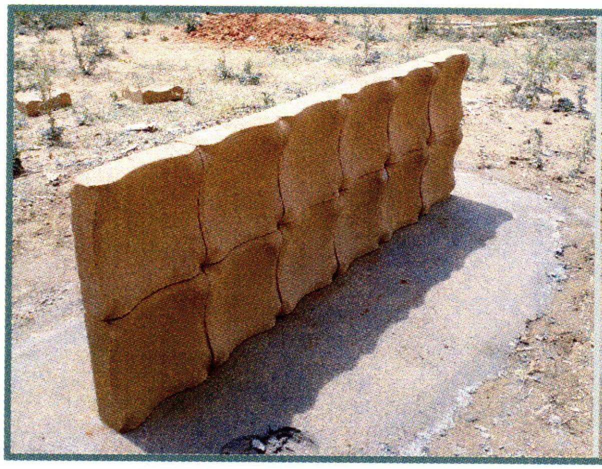
As soon as the team successfully produced the first group of blocks, the architect was so eager to construct a small mock-up consisting of eight blocks. He used simple *stack* bond to make this mock-up. The point was to see how the profile curves fit together, and how the sun light, shade, and shadow will move over the surface of this wall. That was after 4 pm and the yellowish rays of the sunset contrasted with the heavy shadows over the soil blocks in an amusing, wavy rhythm. The architect was satisfied with the preliminary results. The curves of the edges did fit well together, despite the expected inaccuracy of craftsmanship due to the use of very simple tools at the preliminary experimental stage.

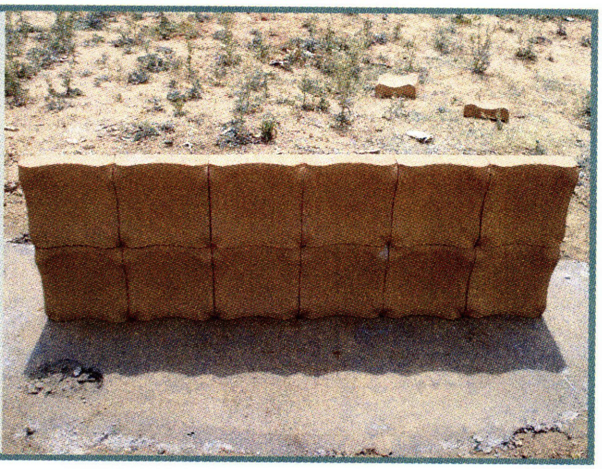
One curve and four walls

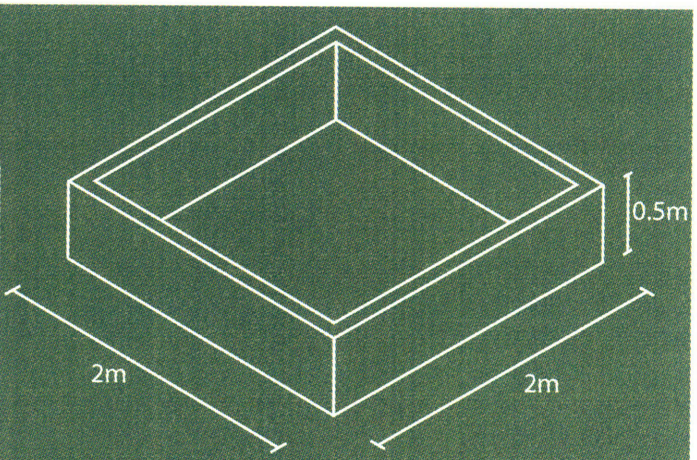
Story Board

Bed

a curve





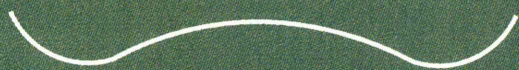


As the first attempt to utilize this type of blocks, the architect had an idea to use the CEB blocks to form the bed frames in the natural resort guest quarters. The beds in the natural resort are 2x2m squares and around 0.5m high. The module of these blocks is 25cm which makes it suitable for the beds. In this case, the bed will be made of 4 walls of this CEB block. Every wall will be 8 blocks wide and 2 blocks high. We can use this simple bond, especially because the wall will not carry a significant load. A Ferro cement slab and a matt will be carried by these CEB walls.

$

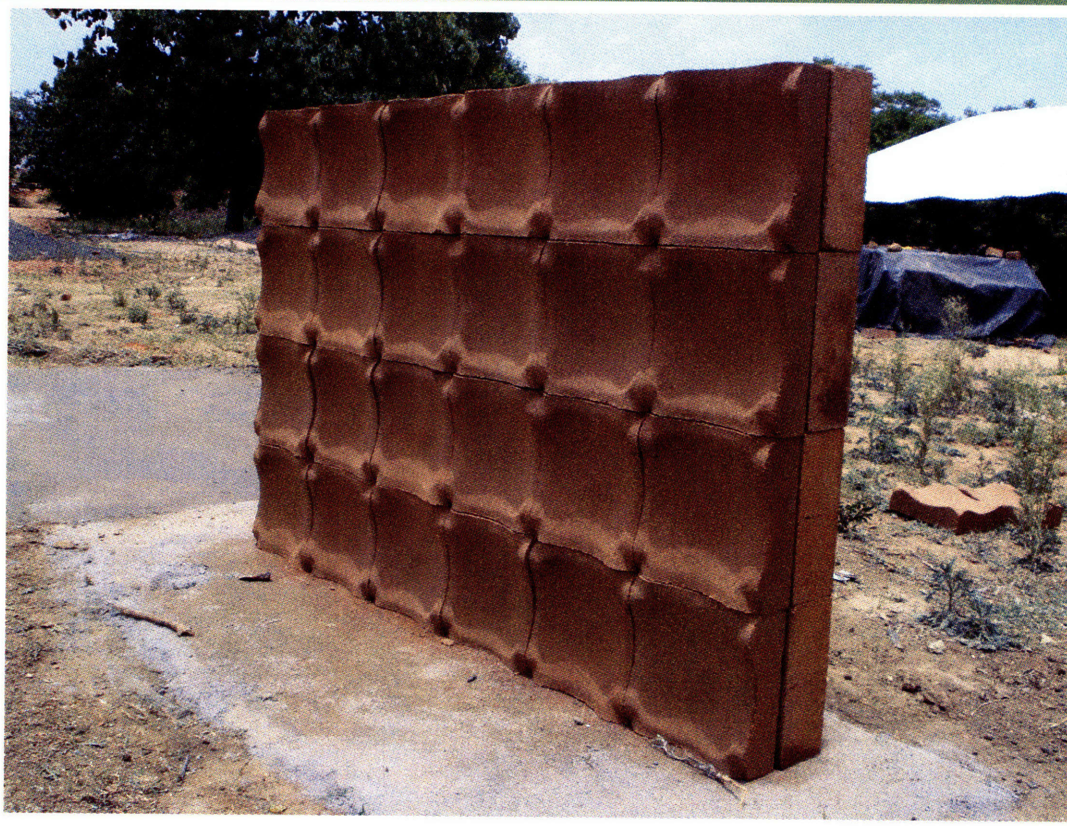
The sponsor liked the idea as he always thought that the bed is very important in the room; therefore, he was very happy that we can give it more attention using these special blocks.

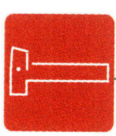
One Curve and Four Walls



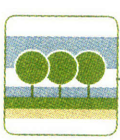
Story Board

Wall 1

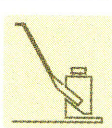




The architect decided to take a further step to utilize this block type with an undulated surface. So he constructed a wall with the simple stack bond. The architect positioned the blocks on site in different angels on site to be able to observe the shade and shadow movement and then selected the most effective orientation.



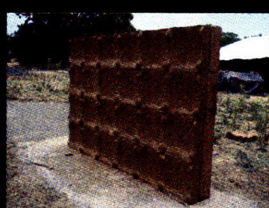
In this case, the site dictated the orientation of the wall to maximize the effect of shade and shadow movement of the earthy surface of the wall.



The production workers from the village loved this wall. They started to come and see it, and then they called it "flower wall."

Climax
of
Story Board

I see the moment of finishing this wall as the climax of this story. On the design level, I had to pause and reconsider my usual design process. On the social level, this was the moment that a new spirit dominated the whole team. On the technical level, this was when we rediscovered the material, by finding that there are very simple and easy techniques to come up with original results.



This *flower wall* is beautiful.

Burshuttum

story board guest

He is a farmer from the same village, who became a friend. He was not working with us. He was taking care of the plants around, and he was watching our work with interest.

It seems that everybody knows about everything in the village Burshuttum and other villagers (whom I did not see before) came to see the flower wall. They are smiling while pointing to it and exchanging comments in Hindi. That should be good.

Burshuttum

Sir, I want you to make a drawing for my home. I am making new home for my son.

Climax
of
Story Board

I want to visit the village.

In the village . . . All people are welcoming me so much, like they know me.
There are some beautiful homes built with adobe.

Burshuttum — You should visit my home and drink tea.

In Burshuttum's home., we had an enlightening conversation:

Burshuttum — This is my home. I will build the home of my son on this part of the land.

Showing me a pile of village fired brick.

This is the fired brick I will use to build the home. I made it myself.

Then he said assertively:

You will make drawings on computer and give it to me, so the house becomes a fixed memory for you visiting us here in the village.

Their vernacular homes are so beautiful. I am sure they just fit their own needs, which I do not fully understand. I can give him some advice and technical support. I am not sure if it is wise to make the whole design.

Climax of Story Board

So, Burshuttum, you are planning to build this house with fired brick?

Burshuttum — Concrete and fired brick.

I really love your house. It is SO beautiful .
You built this with mud brick, right?
Did you design it yourself?

with a voice full of pride ...

Burshuttum — TRUE

You are a good designer yourself. I am not sure if I can design something for you better than you can, but we can discuss the design together.

maybe a minute passed in silence ...

then I turned to the rest of the villagers around asking them ...

Will you all build your next homes with concrete and fired brick?

all said almost in one voice — TRUE

Climax of Story Board

NOT AGAIN . . . I can imagine what will happen to this village.

It is hard for me to understand, rationalize, or immitate the sublime natural beauty of such a village.

I feel that their architecture just fits them, their clothes, their lifestyle, and their environment. Everything is harmonious.

I even heard several times that their mud brick homes are thermally comfortable during both summer, and winter.

Those villagers have developed their own architecture built with earth through a process that probably took hundreds of years. Once they construct their homes with concrete and fired brick, they usually produce ugly unfinished poor constructions. I have seen this happening in many villages in Egypt, and then India. That is so sad.

Climax of Story Board

At this point, I did remember something important.

The environmental cost of fired brick (in general) is fundamentally higher than the environmental cost of CEB, or earth materials.

The environmental cost of the village fired brick is fundamentally higher than the the environmental cost of the kiln fired brick, why?

After watching the production of the village fired brick, I am not surprised. They burn mud brick, which is made of top soil that is rich of organic substance (bad for brick), for three continues days in the open. The waste of brick is huge (around 15%). The CO2 emission and energy consumption are extremely high. Using top soil means wasting the soil suitable for agriculture.

This is clearly an extremely harmful practice to our continuously degraded environment. It is widespread in India as well as other developing countries, however outlawed sometimes. Our planet is already in peril. What will happen if all these villages in India and many other developing countries have been rebuilt with village fired brick and concrete?

CEB environmental cost compared to kiln fired brick and village fired brick in India:

Pollution emission
2.4 times less than kiln fired bricks.
7.8 times less than country fire bricks.

Energy consumption
5 times less than kiln fired bricks.
15 times less than country fired bricks.

A study from development alternative, New Delhi.

Climax

of

Story Board

I should try to convince those villagers not to rebuild their village with concrete and village fired brick.

It seemed that I am in a good position to do so. I was sitting on a bed that Burshuttum specially brought for me. They were all sitting on the floor, and when I tried to set with them, they strongly refused to the extent that made me feel that I might have offended them by trying to do so. They are calling me "Saheb", which is a title that expresses great respect. Apparently, they also respect my work, and ask for my advice to help them develop their homes. I cannot be in a more commanding position to give them a convincing advice.

Burshuttum, I really like your mud brick home. It looks very beautiful, concrete will probably look ugly like the small city nearby. Do you want your beautiful village to look like that?

Your house is cold in summer and warm in winter. Your new concrete house will probably be cold in winter and very hot in summer, and you know that, right?

And what about the tradition of the village? The style of your buildings is the tradition of your fathers and grandfathers. If you all make your village looks like the small poor cities that we usually see on the high roads in India, you will lose your tradition.

For me as a guest or a tourist, I respect and enjoy your tradition. If this place looks like a city, I will not be here visiting you in your home right now. Don't you want other foreigners to respect your place?

And ... Can you imagine yourself wearing ... jeans for example, instead of your clothes? I do not see this as that right picture. It is somehow the same. I see you setting in this house wearing those clothes look very well. This is a good picture, I think.

Burshuttum and the others agreed continuously with me on every single point. They know that the concrete house will be hot in the summer, and they do not see themselves wearing jeans; they like their clothes. So, I thought that I have convinced them.

After a pause, Burshuttum said with strength and confidence:

Burshuttum

Sir, I lived in a house made of mud; my son will live in a house made of concrete.

Climax

of

Story Board

Flash Back . . .

At this point, I remembered another dialogue with another villager, but this time in Egypt.

While drinking tea with him in his house, we talked about different subjects, including the deteriorated conditions of their village. I said that I would travel to the US to study, but when I come back, I might be welling to work with the villagers using their adobe. He looked directly at me and said assertively, "NO, YOU COME BACK TO US WITH A NEW TECHNOLOGY".

I had similar conversations with several villagers. They all lead to the same conclusion: Most of the time, the villagers do not want to stick to their traditional techniques and materials forever. They are watching the TV and they want to catch up. The argument of "keeping your tradition" does not seem to work. They want new technology, and we have to try to offer them a viable, sustainable, and convincing advanced technology.

So, Burshuttum, what do think about the technology that we are using for the natural resort. You said that you like the flower wall. We also made some experiments in front of you that show that it is a strong material that resists water. CEB is a new earth technology. Would you like to use this technology to build your new home for your son?

Burshuttum

Yes, this is a good new technology. It is strong and the flower wall looks beautiful.

Most villagers used mud brick or adobe in their traditional homes. Probably they think that it is a weak and old material. They want to move to new technology. They go to concrete because it is the clear available choice. In this case, CEB shows its true potential. It is an earth technology, but cannot be described as traditional. We can easily represent CEB as a new, developed, refined, or advanced earth technology that is strong and water resistant. According to my experience, this is a very convincing argument, especially if the architect managed to prove to the villagers that it is a beautiful material as well.

One Curve and Four Walls - Walls 1&2

Story Board

Wall 2

a curve

Wall 2 - *Running Bonds* (two types)
While the first one is the usual *running bond*, the second one is completely dependable on the curve profile of the blocks. This wall is constructed using two different bonds (shown in the next page). These bonds are stronger than the stack bond especially for a single layer wall, because these two bonds do not produce continuous vertical mortar joints. The only problem with this bond is the difference between the overlapping curves of every two adjacent blocks, which might make this wall more susceptible to weathering.

Wall 1 - *Stack Bond*
This wall is constructed using the stack bond. It is not a strong bond because it allows continuous vertical mortar joints; however, the bond could be improved with vertical reinforcement hidden in the joints. Additionally, this wall was designed to be a double wall, which means that the second layer can shift to strengthen the whole wall.

One Curve and Four Walls

a curve

Wall 2
running bonds
mentioned on the
previous page

Bond 2

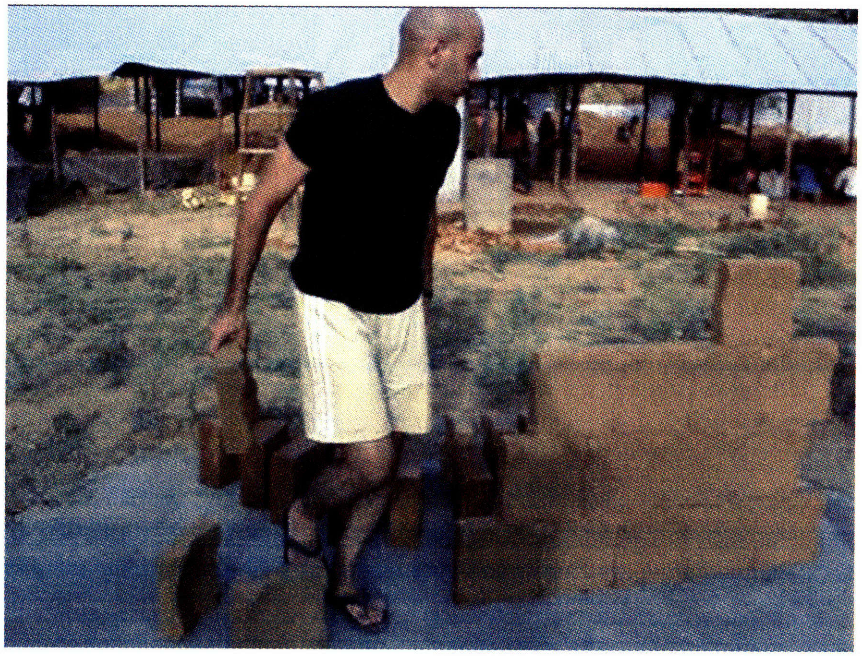
Curve Dependent Bond

Bond1

Usual running bond
(half way - half way)

A Conversation with a Block

Pause



The architect here has taken the role of the mason, and constructed this mock-up wall. While working on the wall he learned some lessons. There are very important factors that have to be taken into consideration while designing a block well as a bond: the weight of the block; its texture; and its ease to be carried, handled, and then laid.

The architect laying blocks himself lead to a change in the bond. To form the first course, he used the usual running bond, where the midpoint of every block on the even course is positioned over a vertical joint between two blocks from the even course (half way- half way). When the architect came to the second bond between the odd and even courses, his hands were automatically compelled by the special design of the block to change the bond. This time the special bond was dependent on the special block.

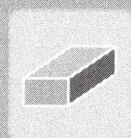
This kind of sensitivity that the architect attained through his hands building the wall cannot be attained through our contemporary computational tools. They are still unable to provide the designer with significant information that has to be fundamentally influential to the design process.

A Conversation with Louis

Pause

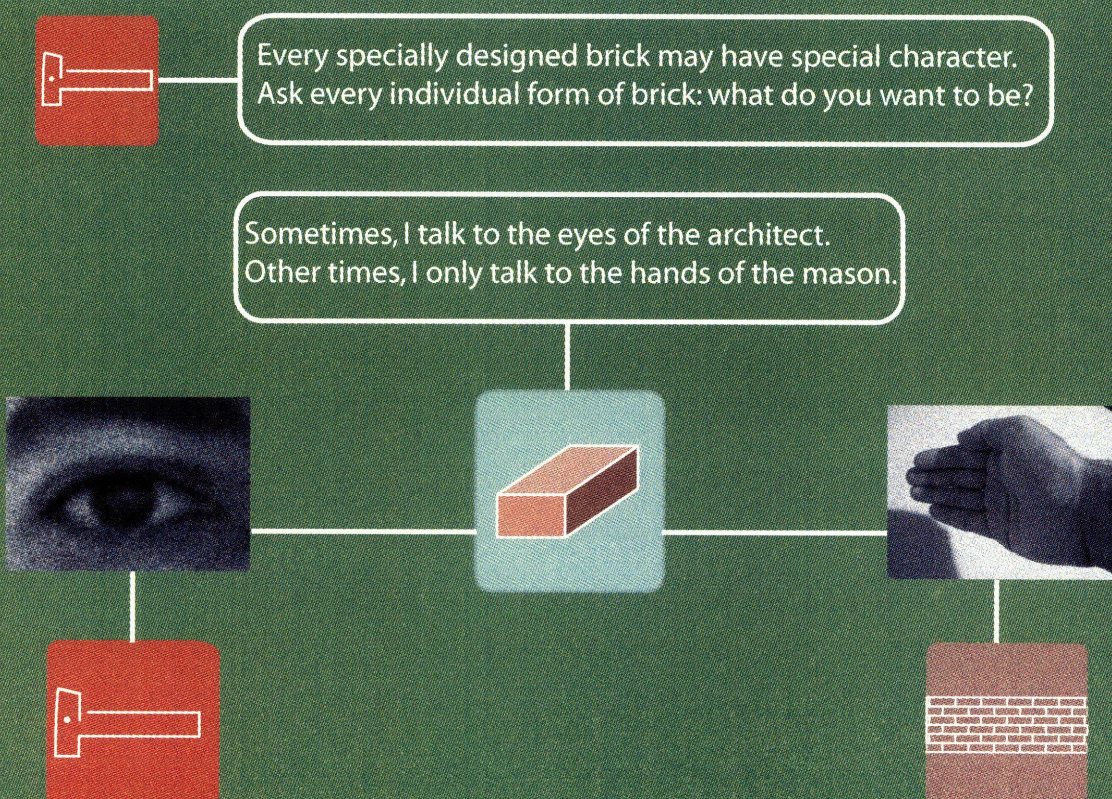
Even a brick wants to be.
Ask brick: what do you want to be?

Story board guest
Louis Kahn



Brick says: I want to be an arch.

Louis Kahn talks about brick in general, the general demands and enquiries of brick. Yet, if we assume that brick does not have a standard form because the architect will extend the design process to the design of the block, then the architect has to listen to the specific demands and enquiries of every form of blocks as well.



The Gentleman Architect & the Master Builder

Pause

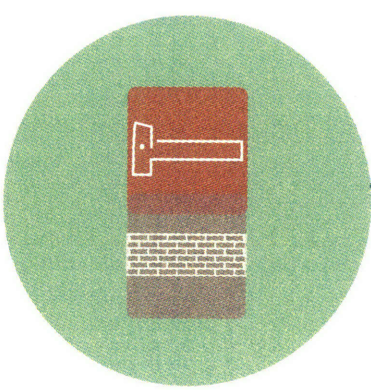
Tomorrow

?

Yesterday
Master
Builder

Today
Gentleman/
woman
Architect

There are clear differences between today's gentleman architect and yesterday's master builder. Both had a completely different professional path, and consequently both attained different qualities. It is hard to predict the position of the architect of the future, Yet I hope that this architect of the future will find a position somewhere between the present and the past. The master builder was in complete control of both the design and construction processes as one united and interwoven undertaking. The master builder had control over the material, the workers, and all the different resources on the construction site. We need the architect of tomorrow to attain some of these qualities if we are serious about a true sustainable design and construction process. Only this type of architect can build with earth, because, working with earth, the architect usually has to be part of the material production and then the construction. Earth somehow refuses gentlemen architects, therefore almost all modern architects who worked with earth have been transformed through the their professional path and attained some of the qualities of the master builder. To develop earth materials, we need a generation of architects who attained some of these qualities, and earth has this ability to create this type of architects. We should find all ways possible to encourage a new generation of architects to try work with earth. Then hopefully earth will take it from there.



The architect, who wants to truly listen to brick, should try to work with his hands sometimes. When the architect does that, she or he becomes the architect and the mason at the same time. This state of unity between the two separated professions according of our understanding today, might be a moment of inspiration.

One Curve and Four Walls

Story Board

inverted curve

Wall 3

What if we just inverse the curve and go through the same process?

One Curve and Four Walls

Story Board

Dialogue

inverted curve

What if we just reverse the line and go through the same process? We might get a very new expressive wall with minimal effort in a short time. It is important to understand that we can do something that to a great extent looks different, but which is actually somehow the same. In this case we used the same curve profile but reversed. The carpenter knew how to make the insert from the curve, the machine workers knew how to deal with this type of wooden inserts, the results somehow are expected and almost guaranteed. So, we can always find derivatives of the same concept to bring variety without introducing a completely original object or process.

For the carpenter, the fact that this new project was somehow a repetition of the previous task was good news. He was confident telling the architect that he will finish by the end of the day, and he did.

Originals and derivatives

Working with craftsmen during this period, I found one word that can best define their attitude: repetition. I noticed that they work, while continuously refining their method until they reach their maximum efficiency. From there on, their hands memorize their optimal process and repeat it. That is why it is always good to give them work that they have done before. It just makes the entire process simpler, more efficient and speedier. But as an architect, I wanted to introduce innovation in every step. That is why I suggest that we can always introduce a few original methods, as well as a few derivatives of each of these original methods. Introducing only original concepts might not be practical in real life construction.

One Curve and Four Walls

Story Board

inverted curve

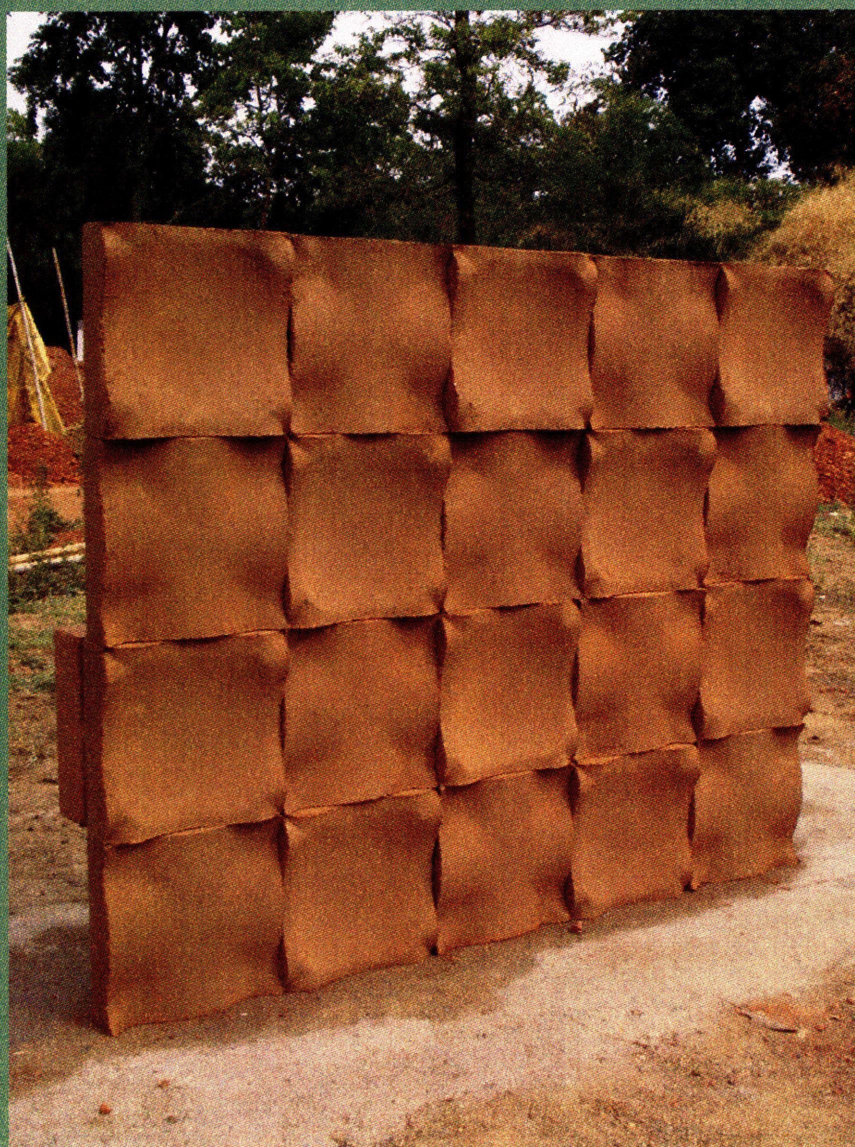
Differences

During construction, finding a derivative of an already established construction process that was successful with specific material, craftsmanship, and tools, will definitely ease and speed the process. Yet derivatives will not necessarily lead to a complete repetition. Differences might appear somewhere on the timeline of the process. In this case, just by inversing the curve, the carpenter first carved a new mold, which was almost the same for him as making the first one. Producing the blocks using the mold accessory and the machine was also the same, but finally laying the blocks was different. Not all of the bonds that worked with the one of the two blocks worked for the second. In this case, the protruding intersections between every four blocks (in wall 3), makes it almost. There will be too much of the block coming outside the wall without enough protection against weather.

Wall 4

the two curves

What if we use the two curves together?

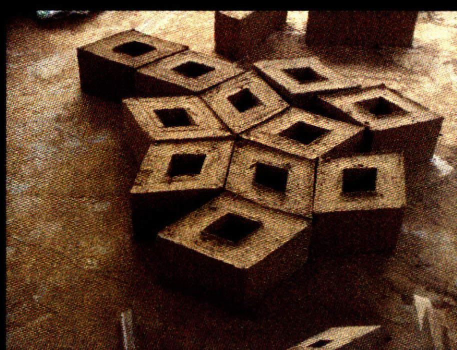


Three walls generated from a single curve.

Everybody is Happy

End
of
Story Board

It was an enjoyable and rewarding venture. Finally, everybody is happy. I am very satisfied about the experiments. CEB proved to me that it is an underused undiscovered material. We can do a lot more with CEB.



The villagers working on the production did like "the flower wall." They started to be more imaginative while storing blocks.

We can make flowers too!

They want to be creative too. They want to be part of the process.

This is a good sign.

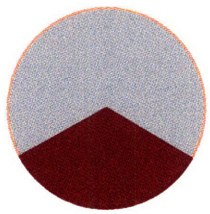
I am very happy to see these walls in reality (not only in computer). Now, I can discuss with you, which walls to use, and in which places in the project.

This natural mud brick with natural color is a good material.

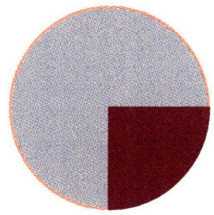
Fifty farmers from the close village participated in this project. They learned new techniques. Eventually, they all have become enthusiastic about the process as well as the final product of the work. They became convinced that the CEB is a material that they can use while building and developing their homes in the village.

Why Earth?

Key Concepts



1/3 of the world's population lives in earth constructions



25 % of the world population does not have access to decent housing

(Statistics from UNCHS)

Social Equity

Almost one-third of the world's population lives in earth homes, yet this high proportion may not reflect the almost imperceptible presence of raw earth construction techniques in the contemporary formal architectural practice or academia. While the main body of the architectural industry favors using, researching, and developing the so-called modern or industrial materials, a small and relatively isolated group of practitioners has been passionately defending earth as the material that will solve our major contemporary problems, like global poverty. Yet, their work has not succeeded at bringing earth to the whole community of architects. Developing earth construction technology may enhance the living conditions of the poor.

CO_2 emissions from automobiles worldwide

6% of the CO_2 released to the atmosphere

CO_2 emissions from Concrete industry

7% of the CO_2 released to the atmosphere

(office of Sustainable Development, Portland, Oregon)

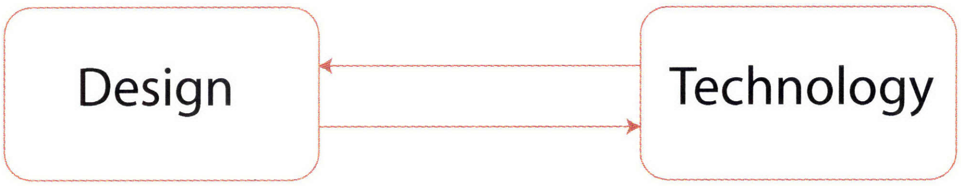
Environmental Sustainability

At the beginning of the twenty-first century, global calls for sustainable development to control global warming and reduce carbon dioxide emissions are becoming increasingly persistent due to the short intervals between Nature's warnings. Therefore, since sustainable construction is a keystone in a global sustainable development, it is imperative that one of two actions should occur: either industrial materials evolve to compete with earth in terms of its sustainability, or sustainable materials like earth evolve to compete with industrial materials in terms of their design capabilities. While the visible first expands outside the architect's range, the invisible second is the architect's responsibility.

Evolving Earth Technology

Key Concepts

A hypothesis



While most earth architects have been preaching for a few decades now for the other architects to *look back* to traditional earth technology because it is sufficient, I argue that only when earth technology evolves to compete with industrial materials in terms of their design capabilities will architects *look forward* to earth. Yet earth technology can never evolve without a fundamental change in earth design approaches, because we can only push technology by challenging reality through imagination. Therefore, pushing technology is the responsibility of the earth designer.

A glimpse at the historical earth architecture in different regions may clearly indicate the unlimited variety of forms, sizes, and construction techniques of earth -- from the vertical and horizontal dugout schools and dwellings in China, to the towering cobe city of Shibam in Yemen, to the rammed earth fortified Ksour in Morocco, to the wattle and daub buildings with their elegant straight lines in Japan, to the directly shaped fluid and colorful earth huts with their fractal compositions in Ghana, to the adobe monumental religious Incan Pyramids in Peru. Although these examples are a drop in the ocean and do not include all of the techniques and forms that earth has already achieved, they sufficiently prove that today's earth architecture can be described as relatively limited. We can conclude that however contemporary earth technology supersedes historical earth technology, historical earth architecture is superior to what we are making today, a phenomenon that has to be rationally analyzed.

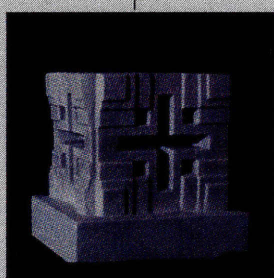
Today, adobe, rammed earth walls, and compressed earth blocks (CEB) stand as the most popular of the major twelve earth construction techniques. During the last few decades, both the ancient adobe and rammed earth production were mechanized. While adobe however mechanized is still relatively fragile, rammed earth with its advanced forms and pneumatic rammers and consequently its ease, speed, and elegance is still practically incapable of tackling the most challenging problem in construction, roofing. And here emerges CEB as the most developed and capable technique with new generations of compressing machines that produce varied block types, shapes, and sizes, with high compression strength, and water resistance, as well as its ability as a type of masonry to efficiently construct all parts of a building. That is the reason why I selected this technology as the starting point. Through my work with CEB, I tried to discover the design approaches and processes that could push the envelop

The Unit, the Element, and the Composition

Key Concepts

Work on the three levels of creation!

	Unit	Element	Composition
	Block	Wall, vault, dome	Wall, vault, dome
Examples	*Wright*	*Diestee*	*Fathy*



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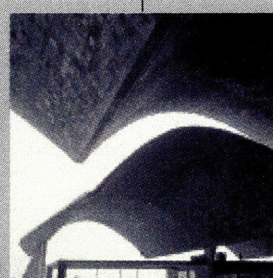

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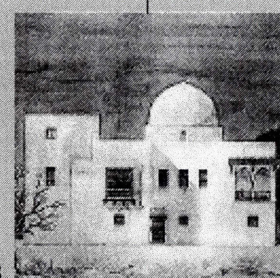


3

There are three levels of creation in all kinds of masonry structures, the unit (brick), the element (wall, arch, vault, and dome) and the composition (the arrangement of these elements); to fully release the full capacity of a masonry structure (in this case CEB), designers should consider working on the three levels. While the twentieth century earth pioneer, Hassan Fathy, working with adobe, has worked on the level of the composition of the elements, consciously he has questioned neither the traditional unit nor the traditional element elements. On the other hand, Eladio Dieste, the Uruguayan engineer and architect, through his quest for the structurally efficient surface using reinforced backed brick and ceramic tiles has questioned the element, and Frank Lloyd Wright in his California textile block houses using concrete blocks has started questioning the unit. It is important to note that in both cases questioning the traditional element or the standardised unit has originated from the pursuit of a comprehension for the essence and possibilities of the material which interestingly led to develop innovative construction techniques. It might be legitimate to wonder why this questioning did not noticeably occur within earth architecture, especially because of the nature of earth construction, which fully integrates the designer in the whole process of creation including material production and construction. Consequently, earth has this ability to relocate today's architect between the gentleman architect and the master builder, an advantageous position to question the unit and the element using the very affordable material.

Vernacular vs. Earth Architecture

Key Concepts

Vernacular Architecture & Earth Architecture

Vernacular Architecture

Earth Architecture

A hypothesis:

Earth architecture has been mistakenly connected to specific vernacular forms. The image of earth architecture is to some extent linked to the image of the traditional domes, and vaults that Hassan Fathy, the pioneer of earth architecture in the twentieth century, used to build with adobe.

I believe that this inaccurate connection is harmful to earth architecture. Architects, who want the freedom to innovate, will not be very satisfied to work with a material that they perceive as restricted to limited traditional forms with specific proportions.

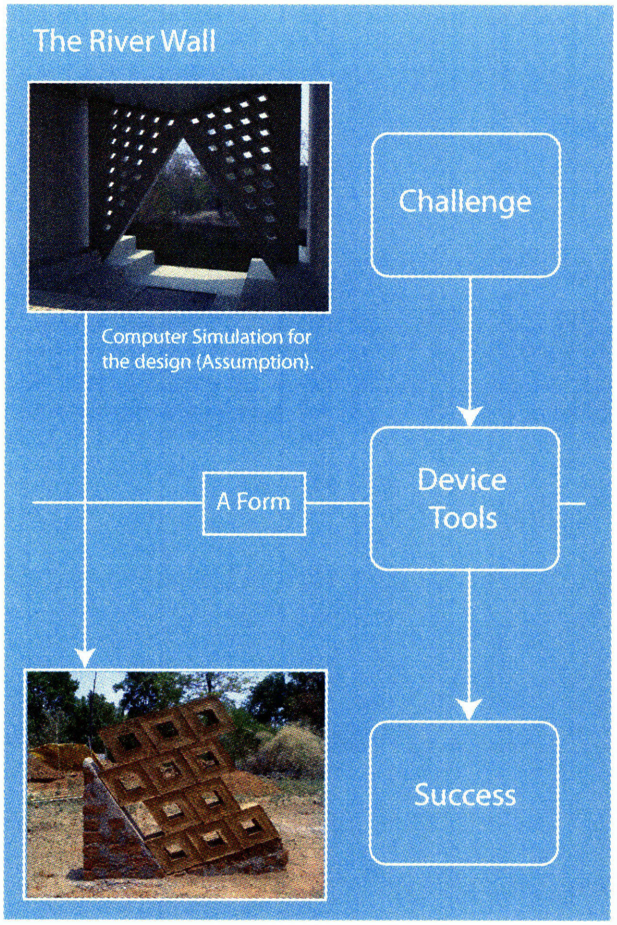
This is a misperception. Earth is a material that can be used in many different ways. Historical earth structures around the globe shows us the unlimited variety of forms and proportions that earth has already produced. Today, with more advanced earth technologies like CEB, we probably can do more.

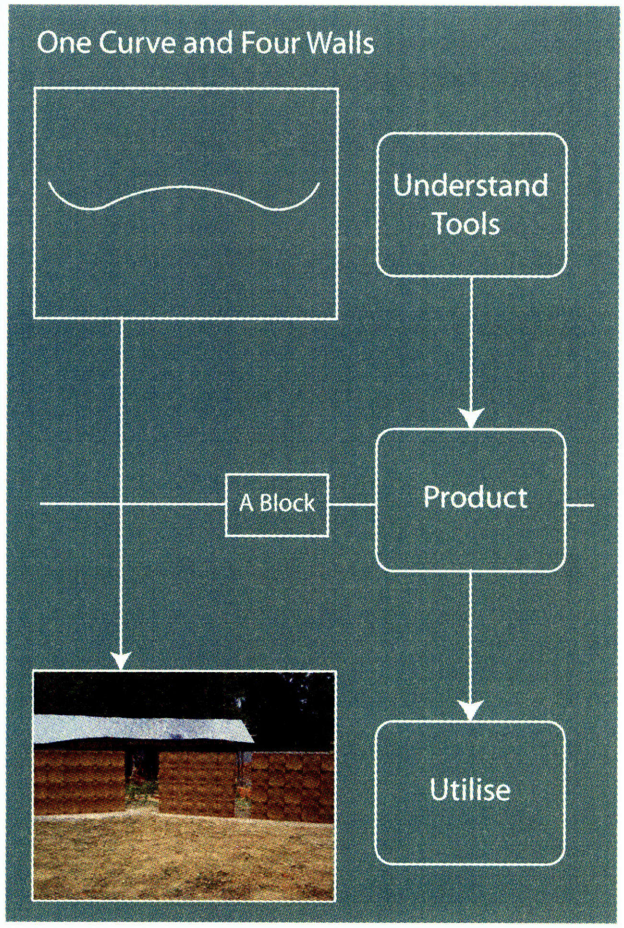
To convince a new generation of architects to consider using earth technology, we have to show them that earth does not have to be restricted to these specific vernacular forms. We have to mentally separate between the image of earth architecture and the image of vernacular architecture. To do so, the earth designer has to work on both the level of the element and unit. Otherwise, she/he will be restricted to the traditional blocks and elements, and innovating on the level of composition will not be enough to separate between the image of earth and vernacular. This hypothesis was a major driving force for my work with earth. Experimenting with CEB, I found simple ways to innovate on both the level of the unit and the level of the element.

The Design Process

Key Concepts

a comparison





In this case, we developed the design using computational tool, before we go to the construction site. The design proposed was an assumption, because we did not know if we could realize it with the tools available on-site. Therefore, the proposed design imposed a challenge. On site, we had to find solutions for this challenge by devising tools and methods through a process of trial and error. Eventually, we succeeded to achieve the pre-proposed design.

While we were working on the production of CEB, and trying to find solutions for the *River Wall* challenge, we started to understand the process of production, the capabilities of the machines, tools, as well as the craftsmen available. This understanding inspired a simple curve, which generated a product (a block). Then we started to speculate variant ways to utilize this product in our project. In this case, we started the design process from the construction site.

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All pictures were taken by the author except:

1) Picture of a block from ennis house taken from ennishouse.org

2) A vault by Eladio Dieste, picture taken from estructuras.com

3) Villa at Fayoum, project painting by Hassan Fathy, Egypt (Photo by Jean-Pierre Cousin)