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Re-establishing place through knowledge: A facility for earth construction education in Pisco, Peru

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Re-Establishing Place Through Knowledge: A Facility for Earth Construction Education in Pisco, Peru

by

Hannah Jo Sebastian

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Architecture
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Dedication

To my Parents, who took me everywhere, taught me I can do anything, and never let me give up. To my Grandparents, who always supported me. And to Raul, for being my best friend through the hardest and greatest years of my life. Epic Win!
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ABSTRACT

Human vulnerability can be characterized as people living with uncertain livelihood options, precariously settled in structurally unsafe buildings. A striking aspect of this vulnerability is the large number of people living in earthen structures within seismically active zones. This reality is exemplified by the earthquake which occurred this past summer around Pisco, Peru. The earthquake caused enormous damage to more than 80% of the adobe buildings. Although confined masonry is the preferred construction technique for families who can afford it, adobe is still the only economically viable alternative for most.

Presently reconstruction efforts are focused on encouraging residents to build with reinforced masonry, but the reality is that once these volunteers leave, or their funding runs out, people living in these areas will not be able to afford to continue with these enhanced types of construction. The goal then, is to come up with a hybrid of earthen construction found in the area that incorporates what is known of structural reinforcement with found or recycled objects that can contribute to improved tensile strength. This hybrid will allow for the rebuilding of Pisco at an affordable, yet highly stable level.
This thesis will begin by visiting Pisco to conduct forensic studies of structural failures with documentation of physical observations and discussions with local institutions that have researched the crisis. Interviews with residents will also give insight into the events and building failures due to earthquakes as well as local construction methods. Readily available resources will be incorporated into the project in a way that should improve seismic resistance. Throughout this process research will be done on current seismic engineering discoveries in conjunction with indigenous approaches to earthen construction in comparable areas around the world. The possible construction approaches will be tested in collaboration with local Universities’ Seismic testing facilities. Once established, this hybrid earthen construction technique will be applied to one of several different building typologies (housing, schools, churches, etc). The end result will be the creation of a building design that establishes an appropriate reconstruction method at an economic level that will reduce the inhabitants’ susceptibility to future seismic disasters.
Figure 1: USGS Earthquake Damage Report of the Pisco Earthquake

As Architecture students, it can be inferred that not only do we have a duty to build safe and habitable spaces, but aesthetically pleasing ones as well. This is a given when dealing with a wealthy client or organization, but what about those throughout the world who go without proper dwellings or consideration of ways to improve the quality of one's life, simply due to the fact that it is not economically feasible? In a world where globalization is bringing cultures closer together and creating greater social awareness, we as emerging architects, should not only use our wide range of knowledge to help the immediate surroundings of our clients, but to find a way to improve the built environment in areas less fortunate.

“According to UNEP’s Global Resource Information Database (GRID) Europe and UNDP, 118 Million people are exposed annually to earthquakes (magnitude higher than 5.5 on Richter Scale) Of these incidences, those most vulnerable are located in developing regions such as the Middle East (Turkey, Iran), Central America, the Andes of South America (Peru, Chile), India/Kashmir, and Central Asia/Japan.” ¹ Due to the economic status of many of the regions located in seismically active areas, there is a greater proportion of mortality, and lower resiliency as far as the countries’ ability to recover from such disasters. When comparing earthquake risk with other natural risks it is informative to see that, while the probability is low, the earthquake risk is far above the risk from other natural hazards. ² Mortality in these regions increases exponentially compared to other disasters often because of remoteness and lack of health facilities, communication and infrastructure, unregulated or informal construction, and most importantly, the economic capacity to build seismically resistant structures.
This implies that earthquake damage increases strongly with decreasing occurrence probabilities, which in turn means that the largest ones are rare but very destructive. “This indicates that at any given location one cannot rely on ‘human lifetime memory’ as a basis for precautionary measures: science is needed instead.” 3 Earthquake disasters are of course caused by the combination of strong ground shaking and buildings having low structural capacity, thus showing a poor performance during earthquake action and being unable to withstand the shaking without damages. Two main factors that therefore can turn an earthquake into a disaster are the vulnerability of (inadequately constructed) buildings, and unfavorable soil conditions beneath the building. The latter will amplify ground shaking effects and in some cases even contribute to liquefaction or sliding. 4

An overwhelming illustration of the impact of these two factors can be seen in the earthquake that occurred this past summer in the town of Pisco Peru. This earthquake took place at the boundary between the Nazca and South American tectonic plates which are shown to be converging at a rate of 78 mm per year. The earthquake occurred as thrust-faulting on the interface between the two plates, with the South American plate moving up and seaward over the Nazca plate. 5

Generally speaking the prevailing construction technique of the area’s built environment consists of a wide range of vernacular (adobe) buildings. Being by definition, non-engineered constructions, they are the result of ancient traditions, improved with time as a response to the requirements of their social and physical environment. Vernacular buildings in turn possess certain specific qualities that radically differentiate them from other types of non-engineered constructions. In
a permanent trial and error process, they are able to reach an asymptotic and
dynamic adjustment to become well-fitted with their surroundings, gradually
changing in response to the new circumstances. The problem arises in the fact
that only certain types of vernacular buildings, notably those with low mass and
properly used tensile resistant materials, may prove seismically adequate for
earthquake resistance.

To complicate the situation even more, as a result of human desire to
move to more urban areas, there are many instances of vernacular solutions
that had proven adequate for often rural, low-seismic environments, but when
reproduced in cities and regions of higher seismicity, the result is very vulnerable
constructions. A unique paradox is that in many cases, the exposure to modern
technology and engineered constructions has worsened the situation. The
problem arises in the fact that it induces the adoption of structural configurations
and construction details, appropriate for modern engineering materials, but when
applied to vernacular materials and construction methods it proves unsuitable. 6

The main concern that arises with these types of structures is that in
despite of the tremendous incidences in terms of loss of lives, the societies at
large are unable to address, much less solve the problem, due mainly to a
lack of resources. Unfortunately in many cases this leaves the communities
unattended in their efforts to rebuild their community after a disaster, highlighting
the issue of inadequate construction practices. All too frequently, after the
widespread destruction caused by a strong earthquake, the survivors rebuild
their homes using materials from the rubble as well as reproduce the same
structural configurations and constructive details as before. Without adequate
technical guidance or supervision, this perpetuates a vicious cycle of death and
destruction. However necessary, any engineering involvement would be doomed to failure unless it is rooted in a genuine appreciation to the wisdom of vernacular constructions as well as pays careful considerations to those processes.

All of these issues bring up the role of earthquake design and the urgent task of improving the seismic safety of vernacular buildings, not only to protect the lives and possessions of the millions of people that still live in these types of construction, but to rescue, improve and disseminate successful solutions.

Requirements for Shelter

Before the particular construction methods are discussed, it is important to address a general framework for what will be achieved in the manifestation of a building. Although as architects it is agreed that the aesthetic quality of a building is of high importance, given the conditions that this thesis aims to attend to, more basic requirements for shelter shall be looked at. While the end result may be a more community-oriented building, it is important to start with one’s most basic needs as a guide for the projects’ ultimate goal. According to the UN Covenant on the right to adequate housing, countries must “recognize the right of everyone to an adequate standard of living for himself and his family, including adequate food, clothing and housing, and to the continuous improvement of living conditions”. The human right to adequate housing, which is thus derived from the right to an adequate standard of living, is of central importance for the enjoyment of all economic, social and cultural rights.

When discussing the right to adequate housing, it should not be looked at as simply the shelter provided by having a roof over one’s head as is seen in the current tent cities throughout Pisco which provide temporary means while...
adequate structures are replaced. All too often in such vulnerable situations where disasters strike, temporary solutions become permanent settlements. These conditions emphasize the importance of creating a method that can be individually implemented that leads to people living somewhere in security, peace and dignity.

As both the Commission on Human Settlements and the Global Strategy for Shelter to the Year 2000 have stated: “Adequate shelter means ... Adequate privacy, adequate space, adequate security, adequate lighting and ventilation, adequate basic infrastructure and adequate location with regard to work and basic facilities - all at a reasonable cost”. 8

While adequacy is determined in part by social, economic, cultural, climatic, ecological and other factors, there are a number of common minimums that should be applied when discussing adequate housing. In general, there should be sustainable access to natural and common resources, safe drinking water, energy for cooking, heating and lighting, sanitation and washing facilities, means of food storage, refuse disposal, site drainage and emergency services. In addition there should be consideration to the Cultural Adequacy of a dwelling, “the way housing is constructed, the building materials used and the policies supporting these must appropriately enable the expression of cultural identity and diversity of housing. Activities geared towards development or modernization in the housing sphere should ensure that the cultural dimensions of housing are not sacrificed” 9

Similar Conditions World Wide

While the focus area for this research is Peru, it is important to note that there are a number of other locations around the world that have similar climactic
and cultural conditions as well as comparable seismic vulnerability. Locally a great deal can be learned from the traditions of Inca and pre-Inca cultures and their approaches to earthen construction. There is also a wealth of information available from the examination of more distant locations mentioned before. Vernacular approaches in these areas range from ‘wattle and daub’, earth bag architecture, and varying techniques for rammed earth.

Of particular interest to this thesis is the historical implementation of earthen construction such as adobe mud blocks, which is of the oldest and most widely used building materials. Use of these sun-dried blocks dates back to 8000 B.C. The use of adobe is very common in some of the world’s most hazard-prone regions, such as Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East, and southern Europe. Around 30% of the world’s population live in earth-made construction, 50% of which are located in developing countries, including the majority of the rural population and at least 20% of the urban and suburban population. By and large, mainly low-income rural populations use this type of construction.

An extraordinary local example of earthen construction innovation can be seen on the coast of Peru around Trujillo at Chan Chan. This culture thrived more than 750 years ago, and was a monument of the building potential of adobe taking on more intricate forms than ever before seen, while at the same time, maintaining the structural integrity of the material. The walls were said to be patterned after the nets with which extensive fishing was done. Upon further observation however one can see how this pattern allows light and air flow- both important in store rooms, while maintaining the strength of the wall system. Such innovations in traditional construction techniques can provide valuable
information in the exploration of an improved hybrid of earthen construction, providing further reason to explore the varying traditional construction techniques found in areas throughout the world that have conditions similar in regard to seismic vulnerability as those found in Pisco.

Available Materials & Techniques

Upon the discovery of possibly applicable earthen construction techniques to this thesis, more localized conditions must be determined to then further the research of a new approach to vernacular construction. A currently explored technique that may provide an impetus for this new technique is Quincha construction. Quincha technology has been used in parts of Peru for many centuries. Traditionally, a quincha house would have a round pole frame which was set directly into the ground, in filled with smaller wooden poles and interwoven to form a matrix which is then plastered with one or more layers of earth. The 1746 earthquake, which had a devastating impact upon the city of Lima, triggered much wider use of quincha due to its improved seismic resistance. The question is, can these previous advances in earthen construction now be taken a step further and integrated with present day, easily accessible materials such as recycled plastics, wire mesh, discarded cans and bottles. The Pontificia Universidad Catholica de Peru has already established numerous ways in which varying forms of mesh can be applied to the exterior of an adobe structure, exponentially increasing its seismic resistance. The next step would be to integrate this application into the connections of the building instead of it remaining a surface treatment. This integration of techniques should ultimately result in a new Hybrid construction method that can become a preventative measure as opposed to a post disaster solution.

Importance of Hybrid Design
Along with the structural stability of buildings, given the intimate nature of vernacular construction there is a particular emphasis placed on meeting more personal needs such as a limited cost of construction. In this case there is not only a concern for achieving a new form that the occupant will be proud of, but also keeping the approach cost effective and within their capabilities to be constructed by hand. By taking the knowledge we have gained from modern technological research in seismic design there should be a way this disjunction between vernacular and technological can be resolved creating a new type of design.

In coming up with this new ‘hybrid vernacular’, there is a multitude of issues that need to be considered beyond the design and stability of the resulting building. Certainly the cost and methods of construction are important as well as the available technology and materials to be used in the structure. If we are to classify these elements into two basic categories; form and context, the challenge then would be to achieve a balance between the two. “The context essentially defines the problems, and the form attempts to be the adequate solution”. Considering the context first, we come up with some criteria for the form to resolve. The first and most obvious issue to address is the firmness or structural stability of the building. Not only must the building resist gravitational loads, but it also must maintain itself despite ground settlements, temperature changes, and in extreme cases, earthquakes and strong winds.

The next important item of concern is service, whether its resulting building satisfies all of the functions required of it by the user, from shelter, to a place for social interaction. In addition to the functional requirements of the
inhabitants, the buildings relationship to its surroundings has an impact on its success. In many cases of structural failure of buildings in an urban environment (in Las Flores, Lima for example) are due to the addition of a building that was not well though out in terms of its affect on the existing context.

New Hybrid Construction Technique

In today’s engineered constructions there are a number of principles that have proven desirable for the creation of an earthquake resistant building. While all of the elements are not required, the more a building employs, the better they will withstand the extreme events of ground shaking and other effects that are likely to occur during an earthquake. The first and sometimes most convenient requirement to achieve is a proper selection of the building site. A second principle to be considered in earthquake resistant design is the lightness of the building. The reason this is important is that the speed induced inertia forces against a building during an earthquake are in direct proportion to the masses of the buildings and their contents. Another reason the weight of a building is important is that the lighter a building is the lower the chances of serious injury or death in the event of the building’s collapse. When choosing construction materials, properties such as strength, toughness, ductility, lightness, viscous energy dissipation, and resistance to weather effects are not only necessary under normal conditions, but crucial in the event of an earthquake. While all are important, for seismic resistance the most important is materials with the capacity to resist tensile forces, as horizontal ground shaking is very likely to induce these stresses.

The most indispensable element of a buildings formal design for proper earthquake resistance is a concern for structural symmetry and regularity. This applies not only to the plan of the building but the elevation as well. The
principles of symmetry and compactness come into play because one objective is avoiding the irregular distribution of forces induced by the earthquake. 18

By applying these rules derived from contemporary seismic research to more traditional construction techniques employed locally, a typological framework can be established. In conjunction with research already being done at some of the universities in Peru, many of these methods can be appropriately tested for their seismic resistance. Once the most successful technique has been determined, it can then be applied to a building within the town of Pisco that is in need of reconstruction.

Application of New Technique

The groundwork in the determination of this new construction technique must begin by compiling the existing seismic research that is available, in an effort to come up with some preliminary assumptions of how earthen construction can be improved. As mentioned earlier, there is a wealth of contemporary seismic research available via Engineering conference articles and the like. The more valuable research to this thesis however, will come from many of the studies being done at the Pontificia Unversidad Catholica De Peru (PUCP), as well as many other local Peruvian Organizations that will be visited during the preliminary research phase.

While this thesis will begin prior to visiting Peru, the idea is to take discoveries such as those done at PUCP about bamboo and chicken wire reinforcement, and attempt to combine them with ideas for integrating recycled objects to improve the structure. Because these assumptions will be made before going to Peru, once there, they will be able to be tested in the same
manner as the previously mentioned projects were. By contacting some of the professors (Marcial Blondet at PUCP and colleagues) involved in this type of research already, the likelihood of coming back with a viable technique is greatly increased. Ideally these contacts made will not only give added validity to the thesis research, but also open up the opportunity for further collaboration as the project progresses.

Another goal for this trip to Peru is to work with some of the organizations that are currently involved in the relief efforts in Pisco such as PREDES- Disaster Prevention and Study Center, Burners Without Borders, and the Earthquake Engineering Research Institute. Because these groups are already involved in what has been happening in Pisco over the last year, they will be able to provide first hand knowledge of the issues and concerns they have for the reconstruction of Pisco. They will also be able to assist in the designation of a particular site within the city that this hybrid earthen construction can be applied to. While the local government will be contacted to direct the site selection to the most needed area, the perspective of an outsider who has been involved in the relief efforts is incredibly valuable to this research.

One of the objectives for the collaboration with these entities is to see if there are ways that what they have been doing up to this point can be integrated into this thesis’ final result. An excellent example is what has been done by the group “Burners without Borders”. With the help of charitable donations, for the price of $1,000 US, they have been able to build a “cornerstone” for the future reconstruction of houses. The cornerstone project consists of a reinforced concrete structure that includes a shower, toilet and kitchen with a wash basin. Because of their limited resources, the organization is aware that they cannot
possibly rebuild all of the homes that were destroyed in the earthquake. The goal is that no matter what the family’s housing situation may be, they will have access to clean, safe sanitation. In addition, the rebar reinforced cement structure acts as a solid cornerstone from which the family can build their permanent home. It would seem that a good possible goal for this thesis would be to use the new construction technique, and teach the local residents how they can properly add on to the cornerstones that are being provided by Burners without Boarders.

Site Research

While a great deal of time in Peru will be spent meeting with individuals and organizations that can help to strengthen the feasibility of this project, ample time will also be allocated to site selection and subsequent research of the immediate conditions that may effect the design of the final building. Of particular importance in this research are site conditions such as soil quality, topography, and climate. While the connections and materials employed in the final construction technique are important, the condition of the foundation that the building is constructed on is crucial to its seismic stability. Because the resulting building is intended to educate as well as rehabilitate, the most common site conditions should be chosen so that the issues to be resolved will be similar to the typical situations that the technique will be employed in.

In the selection of the particular building and site, it is important that what is chosen will not only address the greatest need (housing, school, religious facility) but have enough exposure so that the educational component in the final construction can be successful in reaching the populace of Pisco. While theses are typically more theoretical, a particular intention for the trip to Peru is to lay
the appropriate groundwork so that at some point during or after the culmination of the thesis, the resulting technique and building can be constructed. By attempting to design something that will eventually be built, the hope is that the result of this thesis will be architecturally innovative, as well as help those in need. By instructing the residents of Pisco how they can rebuild their city independent of relief organizations they can create improved and seismically stable living conditions without having to wait hopelessly for relief to come.

By retrofitting and strengthening key facilities within a community such as schools, hospitals, churches, etc, a sort of “Safe House” can be established for the residents in the event of an earthquake. Ultimately it is the anticipation of this thesis that the discoveries made in construction innovation can be used to improve the conditions of those living in vulnerable seismic areas. By keeping the cultural traditions, values and economic situations in the forefront of the project, the resulting building and technique should be something that not only teaches improved seismic stability, but becomes a new type of vernacular. By using techniques that are already in use, and combining them with contemporary approaches, it is hoped that the new hybrid will be widely employed and become a preventative measure as well as a source of pride to an already vibrant area that has fallen upon difficult times due to an uncontrollable natural disaster.

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4 “Project 3: Seismic Hazard, Risk and Loss.” Accessed April 15, 2008

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Marco Mezzi, P. Verducci, J. J. Liu,”Metropolitan Habitats and Infrastructure” Innovative Systems for a Sustainable Architecture and Engineering. (Shangai, 2004), 12

Marco Mezzi, “Architectural and Structural Configurations of Buildings with Innovative A seismic Systems” proceedings of the 13th World Conference on Earthquake Engineering (Perruggia, Italy 2004), 24
Chapter Two
Case Studies

Figure 2: Photo taken at entrance of Tambo Colorado Ruins in the Ica Province
Adobe brick forms and Composition Construction Case Study

Abstract

In many developing nations around the world, Adobe or Earthen construction is the method of choice for a majority of the lower income people. Earthen constructions have many inherent advantages such as widespread inexpensive fulfillment of housing requirements, passive thermal capacity, strength and security of the monumental constructions, and locally available construction materials and methods. Along with these advantages, there are a number of intrinsic issues associated to the fact that many of the hot and arid temperature climates in which earthen constructions are found are also highly active seismic zones. Although a great many advances have been made in seismic design, there is a disconnect between contemporary construction methodologies, and those techniques available to the common family in a developing nation. This case study focuses on the Adobe construction methods found in Peru and particularly studies some of the building failures found in Pisco Peru after the Earthquake on August 15, 2007. After identifying two of the failure points, the strength of the individual adobe blocks, and the connections between the blocks forming the wall system, tests were conducted to see if varying the composition and the form of the blocks can help to create a stronger adobe brick wall system.
Introduction

The Problem

The Pisco earthquake on August 15, 2007 caused enormous damage to earthen buildings in the affected area. Although confined masonry is the preferred construction technique, because many families cannot afford it they are forced to build with adobe construction; most houses over 50 years old are made of adobe. “In Pisco, more than 80% of the adobe houses collapsed or sustained heavy damage. this was due to the perverse combination of mechanical characteristics of adobe walls: they are massive, weak and brittle. Since they are massive, they attract large inertia forces during seismic shaking, which they are unable to resist because the masonry is weak, and brittle failure occurs without warning. Furthermore, it seems that the adobe blocks and mortar in Pisco and the surrounding areas were made with sandy soil, which did not have sufficient clay to provide good adhesion between mortar and adobe blocks.”

Figure 3. Street in Pisco three days after the earthquake. The house at the far right, undamaged, was made of confined masonry.
In addition to the failures of the individual adobe bricks, a number of building failures were attributed to the failure of the joints between blocks (at the mortar) or between wythes of blocks. Many of the older buildings' walls are not provided with additional reinforcement to withstand seismic forces. In addition the duration of shaking in this earthquake -about 100 seconds- contributed to the many collapses. While a great deal of research has been done on vertical and horizontal reinforcement of adobe constructions, through visual observation of many of the building collapses, it can be seen that these reinforcing strategies are not integrated into the system as well as may be possible. The result is walls that have a surviving skeleton of bamboo (the typical reinforcement strategy), yet the adobe bricks that were laid on either side of the walls have still failed at the mortar joints.

Figure 4. Typical building damages to un-reinforced adobe buildings

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3 Figure 4. Typical building damages to un-reinforced adobe buildings
Hypotheses Part 1

Through experimentation with additives such as plastic fibers, higher concentration of clay, as well as other ‘plasticizers’ into the adobe bricks themselves, the elasticity, tensile strength and bonding capacity of the individual bricks can be greatly increased.
Methods

Preliminary Experimentation was done by varying the clay, sand, Silt, and organic materials (straw and cow dung) the goal was to become familiar with the existing adobe making techniques in use in Peru. While the first series of samples were made attempting to have an ‘ideal’ and higher clay content for making bricks, the second series of samples were made with a higher sand content in an attempt to properly replicate the previously mentioned higher sand content found in Pisco. Generally speaking, the higher the clay content found in the adobe, the greater the binding force within the individual bricks.

The loam composition of the bricks has been determined through basic sedimentation tests which can be seen below:

![Adobe Sample #1: Replicating the “ideal” loam composition](image1)
![Adobe Sample #2: Sample #1 with additional Sand](image2)
![Adobe Sample #3: Sample #1 with added Hay](image3)

![Adobe Sample #4: Sample #2 with added Hay](image4)
![Adobe Sample #5: Sample #3 with added cow dung](image5)
![Adobe Sample #6: Sample #4 with added cow dung](image6)

Figure 7. Adobe block Loam Samples
Additional Samples of each loam have also been set aside for laboratory tests to determine the exact composition of each. Knowing the composition of these samples will not only assure accurate reproduction, but it will also allow for comparison with adobe blocks that will be later collected in Pisco. At this point only the sedimentation tests have been completed, however after the optimal curing time has been achieved (7 days) the individual bricks will be further tested, (mechanically) for their compressive strength and tensile resistance (binding capacity).

Figure 8. Adobe Block Loam sedimentation tests
Conclusions

During the experiments a number of process related issues were resolved. With the first, ‘clayey’ soil, a greater amount of water was needed in order to get the loam to an easily workable consistency. While the higher water content was advantageous for mixing, the loam was quite difficult to get out of the mould. Another issue with Block #1 was that as it has been drying; cracks have already appeared due to the shrinkage of the block. The second sample which had higher sand content was also made with less water added, making the mixing of the loam much more difficult, but fewer, smaller cracks have appeared this far as the block is drying. With the sandier composition of Block #2, it was also much easier to handle as far as forming it into the brick as well as removing the form.

In loam composition #3 and #4, similar observations were made. In both instances the addition of hay made the loam more difficult to work with, but as the hay absorbs some of the additional moisture in the loam, it not only softens, but created what seemed to be a very strong, fibrous loam. In comparing the sandier (Block #4) to the block with more clay (#3) the hay seemed to be more workable in #4. The clay content in Block #3 seemed to become too sticky and proved more difficult in the forming process. As of yet, Blocks #3 and #4 seem to be drying at about the same pace, both without cracking.
The final samples (Blocks #5 and #6) were changed by the addition of composted cow dung. In the mixing of these looms, it can be felt what a strong bonding agent the cow manure is. There seems to be a great deal of plasticity in these samples, and the addition of the dried manure further absorbed the excess moisture, making them even easier to work with, while clearly increasing the bonding within the blocks themselves. Again the sandier soil (#6) was easier to work with, and so far blocks #5 and #6 seem to be drying with similar results- no cracking and minimal shrinkage.
Hypothesis part 2

By changing the formed shapes of the individual adobe bricks, new wall systems can be created, reducing the occurrence of continuous mortar joints, and thus improving the seismic stability of the walls with or without additional cane reinforcement.

Methods

By first studying various brick forms that can help to reduce the consistency of horizontal or vertical mortar joints, possible new systems can be achieved. Once possible shapes have been determined via two dimensional sketches, wood blocks were created in the general proportions of 1:2, representing a full scale block proportion of 12" by 6", depending on the final shapes. These blocks were then used representing masonry patterns that when laid will result in a minimum of 12" (30 cm) thick walls which is generally considered the minimum width for an adequate load bearing (exterior) wall. The configurations needed to meet the following criteria:

1. There are no continuous horizontal or vertical grout lines
2. While the system may work for one wythe, they must also be functional for a two wythe system in order to achieve the 12" wall thickness.
3. When accomplishing this 2 wythe system, the same horizontal and vertical grout conditions should apply.
4. The pattern should be simple enough to allow repetition approximately every 2’ (allowing for typical wall heights of 8’, 10’, 12’, etc.)
Conclusions

While a number of block forms were tested, the most applicable form found this far was an “L” shaped block that can be arranged in numerous patterns as can be seen below:

![Figure 12. “L” shaped block system possibility #1](image)

![Figure 13. “L” shaped block system possibility #2](image)

In each of the Block Systems above, all of the requirements were met except #4, a consistent pattern had not been achieved in a reasonable amount of repetitions. Upon further investigations and computer modeling the following System was devised using the “L” shaped block typology:

![Figure 14. “L” shaped block system possibility #3](image)
While one sample of the “L” shaped form was made out of loam sample #6, once further tests show the structural adequacy of the different looms, more bricks will be made out of the “L” form to test the system proposed with the wood block model. The new adobe blocks will again be individually tested for compressive and tensile strength (ductility) to determine that the differences in shape do not reduce the capacity of the bricks as proper construction materials when compared with the traditional adobe brick forms. Given that the new brick forms perform as well as the traditional rectangles, these shapes can begin to look at the wall construction method as an integrated system to further strengthen the buildings seismic resistance.

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2 *Learning from Earthquakes The Pisco, Peru, Earthquake of August 15, 2007; EERI Special Earthquake Report, 5
3 Taiki Saito Quick report of building damages in 2007 Peru Earthquake (Building Research Institute August 24, 2007), 4
5 Blondet, Marcial “Behavior of Earthen Buildings during the Pisco Earthquake of August 15, 2007”, 5
6 Gernot Minke, Building With Earth (Basel, Birkhauser-Publishers for Architecture; 2006), 65
7 Minke, 137
Improving Durability of Earth Construction: African Case Studies

Abstract

Earth Constructions, in their varying forms are one of the oldest building materials with Mud brick houses dating from 8000 to 6000 BC discovered in Russian Turkestan and Rammed earth foundations dating from 5000 BC in Assyria. (Minke, 11) Despite its widespread use through out history, there are a number of issues that lead to a resentment of traditional earth construction. One of the main issues is the durability of the material, which leads to more frequent maintenance, and a perception that their traditional houses do not qualify as real houses when compared to those built with “modern” materials such as bricks and concrete. Aesthetically, the distinctiveness of Adobe brick construction found throughout Peru tends to make the differences between earth and masonry construction quite obvious, and leads to the perception that earth homes are inferior.
Introduction

The Problem

While it may seem that the “modern” construction methods are the solution, there are a number of issues that arise in these instances;

- Because of the higher cost of construction, often these homes are not built as well as they should be due to the need to ‘cut corners’ in order to stay within budget.
- Higher internal temperatures in summer,
- Lower internal temperatures in winter,
- Condensation and humidity issues,
- The possibility of consequent health problems.  

Hypothesis

It seems that upon examination of earth construction, there are acceptable ways that new dwellings can be constructed using traditional materials and building techniques, that will have improved performance with regard to weatherproofing, and durability, as well as have a required maintenance regime closer to that of conventional construction. These new buildings can be built in a way so that the earth construction methods are not only known, but highlighted, showing more reliable and construction possibilities at a comparable cost to traditional earth construction.

Research

One of the main causes of the reduced durability of earth construction is shrinking and cracking. Due to the evaporation of water used in the preparation of loam mixtures, shrinkage cracks often occur. There are generally acceptable shrinkage ratios that directly relate to the water content, kind and amount of clay minerals and grain size and distribution of aggregates. “The common linear shrinkage ratio is usually between 3% and 12% with wet mixtures (those used for
mortar and mud bricks) and between 0.4% and 2% with drier mixtures (used for rammed earth, compressed soil). There are a number of ways that shrinkage (and subsequent cracking) can be reduced, but care must be taken when making these adjustments as improvements to certain characteristics can decrease performance in other aspects (tensile/compressive strength, etc.)

Another cause of reduced durability is that Loam is not water resistant so it must be properly protected against moisture. Again there are a number of solutions that can suitably weatherproof an earth building, ranging in cost from designing adequate overhangs and plinths, sealing walls with varying types of surface coatings, and stabilizing loam mixtures with varying additives.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Average density, soil erosion and water absorption of the cement and the lime-stabilized soil bricks produced from Mahalape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Ratio of stabilization (%)</td>
</tr>
<tr>
<td>Cement</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
</tr>
<tr>
<td>Lime</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
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<tr>
<td></td>
<td>15.0</td>
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<table>
<thead>
<tr>
<th>Table 3</th>
<th>Average density, soil erosion and water absorption of the cement and the lime-stabilized soil bricks produced from Tsabong soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
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</tr>
<tr>
<td>Cement</td>
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</tr>
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<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
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<tr>
<td></td>
<td>15.0</td>
</tr>
<tr>
<td>Lime</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>15.0</td>
</tr>
</tbody>
</table>

As observed in the first case study, one of the most economical ways to reduce the shrinkage ratio with little impact to other properties is to add fibers to the loam mixture. In the aforementioned case study hay was used with good results, while other fibers such as animal or human hairs, sisal, coconut, bamboo, etc have also shown to significantly improve the binding force of the mixtures and in turn reduce shrinkage. In a series of studies done by the Department of Civil Engineering at the University of Botswana, a number of stabilizers were experimented with in order to develop cost-effective approaches to improving the durability of earthen construction. In their tests done with stabilization via...
natural fibers, the fibers act as reinforcing material in the same manner as the fibers used in fiber-reinforced concrete, and “hinders cracking upon drying by distributing the tension arising from the shrinkage of clay throughout the bulk of the material” \(^3\) An important concern with the addition of such natural fibers is that the fibers in the loam mixtures can rot if they are not kept dry and properly encased in the loam. In addition to the fiber content, cement, lime and bitumen were used to stabilize the bricks, and tested for their amounts of water absorption, loss of soil, and disintegration.

Although not shown in the tables because they were rendered “unsuitable for use” and considered “unacceptable in terms of water erosion” \(^4\) it should be noted that cow-dung and bitumen stabilization was also measured. The cow-dung stabilized bricks took a longer time to disintegrate in water than the un-stabilized bricks, and the bitumen stabilized samples did not disintegrate at all, but did develop large cracks. Despite the improved performance when compared to the untreated specimens, they still failed completely when dropped from a height of 300 mm (the lime and cement stabilized bricks did not.) It should further be noted that the addition of Lime to the bricks increased the overall strength; however it increased the amount of water absorption which would eventually lead to deterioration. \(^5\)

Thinning loam mixtures by adding Sand or other larger aggregates has also shown to reduce shrinkage and cracking because it reduces the relative clay content, and the amount of water that can be initially absorbed (reducing the total evaporation). \(^6\) The main concern with thinning the mixtures with such measures is that while larger aggregates can improve compressive strength, it tends to decrease the bonding strength of the blocks, which in turn can have negative
effects on the ductility of the wall system and can lead to poor performance in seismic conditions. In situations where the loam mixture is thinned out by sand or aggregates it can be advantageous to also add natural fibers to have a dual improvement in the overall permanence of the resulting construction.

In an Algerian study similar to the one in Botswana, two observations are important to note. When testing the effects of fiber stabilization, it was found that a decrease in shrinkage is noted with the subsequent increase in fiber length. “This could be attributed to the sufficient length of the straws for the bond stresses at the interface straw-soil to develop and hence to oppose to the deformation and soil contraction”.  

In addition to the fiber reinforcement, the effects of four different water repelling coatings are measured after they are applied to the surfaces of each wall section in three layers then “subjected to water showers for two hours from a distance of 0.18 m at a water pressure of about 1 bar”. 

Figure 17 & 18. Shrinkage variations dependant on fibre fraction

Figure 19. Effect of Fibre length on shrinkage with fibre fraction
The Results of these tests are shown below, and indicate that the cement mixture with polymers was the most durable solution, while lime-cement application performed better than the lime only and soil only solutions.

<table>
<thead>
<tr>
<th>Type of coating</th>
<th>Soil</th>
<th>Average water absorption (%)</th>
<th>Main visual observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime render</td>
<td>A</td>
<td>-</td>
<td>Debonding of the coating</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>9.2</td>
<td>Surface erosion and cracking</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>8.5</td>
<td>Same as soil B</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>9.6</td>
<td>Same as soil B</td>
</tr>
<tr>
<td>Lime-cement render</td>
<td>A</td>
<td>4.2</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.9</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.7</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>4.1</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td>Soil render</td>
<td>A</td>
<td>11.6</td>
<td>Systematic cracking</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>10.3</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>9.4</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>10.5</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td>Cement render with polymers</td>
<td>A</td>
<td>3.9</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>3.8</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.7</td>
<td>No visible distress signs</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>3.6</td>
<td>No visible distress signs</td>
</tr>
</tbody>
</table>

*Figure 20. Summary of block durability test results*

In a different study also performed in Algeria, the focus was on measuring the performance of compacted cement-stabilized soil. In these experiments, typical soil from the region was used and “Ordinary Portland Cement type CEMI 32.5 was used for chemical stabilization”. While these tests were focused more on improving the compressive strength (which is the topic of a later case study) there were important observations made with regards to the shrinkage ratio and the water permeability, both crucial to the durability of earth construction.
In the shrinkage tests, the cement stabilized soil shrinkage was reduced by nearly 20% for the 6% mixture and 44% for the 10% mixture. It can also be seen that the first four days are when the most rapid shrinkage occurs in all three specimens, showing that proper curing during this time greatly reduces the amount of drying shrinkage.  

![Figure 21. Effect of Cement Content on Shrinkage](image)

In addition to the shrinkage tests, the effect of cement content on the water permeability of the loam was quite interesting. The experiments show that “The water permeability coefficient decreases from $14 \times 10^{-8}$ to $0.27 \times 10^{-8}$ m/s when cement content increases from 5% to 20%.” This indicates that the addition of cement to the soil mixture greatly reduces the water permeability thus increasing the overall durability.

![Figure 22. Effect of Cement Content on Water Permeability](image)
Conclusions:

In all three of the aforementioned African case studies, it can be seen that the perception that earth construction is not as durable as masonry construction can be overcome with the addition of a number of different stabilization methods. While the construction budget largely determines the material additives, the addition of hay and small amounts of cement are clearly feasible and readily available solutions that can be applied to earth construction in Peru. In many cases, techniques used to improve the durability of earth construction such as the addition of natural fibers has also shown to improve the overall strength of earth bricks solving both the issues of Durability and structural strength in one step. Given these findings, further research can be made on the effectiveness varying types of constructions such as rammed earth and wet-loam procedures when used in conjunction with these improved loam mixtures to create a holistic approach to improving earth construction approaches.
Overcoming Structural Issues of Earth Construction: Reinforced Concrete Case Study

Abstract

“If we are to prevent new calamities, the profession shall have to amend its practices. From the start of professional training a student must be made conscious of the need to see structure as an integral part of the project and not as some nuisance that the structural designer adds to the architectural project... they must not be viewed as mere add-ons”. Christopher Arnold [1].

Reduction of building and contents damage, personal injury and loss of life in the event of earthquakes are crucial considerations that should be integrated into the design of a seismically stable building. Because there has emerged a disconnect between the role of the architect and the engineer, all too often the building is designed with little regard for the structure, then the engineer is expected to run the appropriate calculations and add the needed reinforcement in order to make the building ‘work’. By integrating a consciousness of these elements in the design of the building rather than adding reinforcement once the design is complete, not only is the result more stable, but the costs should be significantly reduced as well.
Introduction

The Problem

1. Structural issues- Earth constructions tend to have poor binding force, and therefore decreased seismic resistance
2. Can have low compressive strength which can lead to structural failure as well as durability issues

Hypothesis

While the precedents for these integrative design and structures come from contemporary seismic engineering, this thesis attempts to take the same approach and apply them to less expensive materials, and vernacular building typologies. By establishing a set of rules by which the structure can be integrated into the design, new ways of approaching seismic design can emerge, and in turn inform more creative solutions while at the same time reducing the amount of damages to the buildings and their inhabitants. When designing a seismicly stable building there are a number of fundamental considerations that lead to a buildings success.

Seismic Design approaches in Concrete Construction:

Using Reinforced Concrete frames as an example; the integral action of beams, columns and slabs, provides resistance to both gravity and lateral loads through bending in beams and columns. Frames built in earthquake-prone regions should possess the ability to sustain significant deformations under extreme loading conditions.
One way to reduce plan irregularities is to separate the building into simple blocks separated by air gaps (also known as separation joints). This type of design allows the simply configured buildings to act independently, thereby avoiding high stress concentrations at corners that often lead to damage.

Buildings with simple geometry in plan typically perform better during strong earthquakes because buildings with simple geometry offer smooth and direct load paths for the inertia forces induced during earthquake shaking to flow to the foundation.

Vertical irregularities - overhanging balconies or setbacks can also cause structural failures during an earthquake because they cause a level of discontinuity.
Buildings on sloping ground where columns are of unequal heights along the slope often fail at the shorter columns. Discontinuities at elements that are meant to transfer loads to the ground are also dangerous; one should design all columns to follow through all the way to the foundation and not hang at any intermediate stories.

Buildings without symmetrical plans are often susceptible to twisting during an earthquake as well as differential settling. Twisting in buildings causes the structural elements to move horizontally by different amounts.

Buildings with differing numbers of columns per floors or unusually tall stories can exhibit soft or weak story behavior (where one floor buckles under the weight of the others).
Reinforced Adobe Block construction: Studies at the Pontificia Universidad Catholica de Peru

Abstract

Based on previous case studies it is clear that there are ample opportunities to improve the durability of traditional adobe construction methods through various additives, compaction, or surface treatments. Although it these methods reduce the deterioration of earthen structures in normal moisture and wind conditions, they do not take into consideration the effect of an earthquake on the durability of a building. The intent of this case study is to research work being done at the Pontificia Universidad Catholica de Peru to determine the options available to reinforce an earthen structure to withstand an earthquake.
Introduction

The Problem

With traditional adobe block construction great care is taken in the forming and curing of the individual adobe blocks to ensure their strength and stability, yet despite these efforts, very few of the adobe homes in Pisco were able to withstand the 2007 earthquake.

Hypothesis

Given the Local residents of Pisco’s the general knowledge of the process of reinforced concrete and concrete block construction, it seems that there can be a similar application of these strategies using readily available materials such as bamboo or the cane mat commonly found in the area.

Research

The first research project developed at the Catholic University of Peru (PUCP) in 1972 consisted of the experimental study of several alternatives for structural reinforcement of adobe houses, made with materials available in rural regions. Eight modules were built and tested, with variations in the construction techniques, in the cane reinforcing system, and in the configuration of wall openings. Each module was tested in several phases to represent a series of seismic events of increasing intensity. The instrumentation consisted of displacement and acceleration transducers to measure the seismic excitation and the corresponding structural response. In these studies it was found that simply the improvement in the construction technique (the quality of materials and labor) by itself increased the resistance and stiffness of the uncracked walls, but had negligible influence after significant cracking occurs.
An additional study was done in which an interior reinforcement made of vertical cane, combined with the placement of horizontal crushed cane every fourth row of adobe blocks was integrated with the traditional method of adobe brick laying. It was found that this method notably increased the seismic strength of the housing modules. “The cane reinforcement almost doubled the maximum horizontal load capacity and, most importantly, increased almost 6 times the lateral deformation of the reinforced walls, with respect to the un-reinforced walls. The cane reinforcement thus provided strength and ductility to the adobe masonry, which is weak and fragile by nature.”

The horizontal and vertical cane reinforcement, was subsequently combined with a solid collar beam at the top of the walls which would prevent the separation of the walls in the corners due to a severe quake and thus help to maintain the structure’s integrity after the resistant walls fail.

While these studies found significant improvements in the seismic stability of newly constructed adobe homes using these methods, they do not address the reality of the large amount of pre-existing adobe homes without any form of internal reinforcement. To deal with this concern the University to collaborate with the Centro Regional de Sismología para América del Sur (CERESIS), to develop simple techniques to reinforce existing adobe dwellings. The proposed external reinforcement was developed to delay the collapse of the structure during a severe earthquake. In the studies different reinforcement materials were tested, such as wooden boards, ½- inch rope, chicken wire mesh, and welded mesh. At the time of this study U-shaped walls were constructed with both reinforced and un-reinforced methods, and the proposed techniques proves to be far superior in their seismic durability that the un-reinforced methods.
Since the time of this study, additional material possibilities have been introduced such as plastic construction mesh (geomesh) and siltation barrier fabric, as well as improved attachments of these elements if they are incorporated into the construction of new adobe dwellings. These experiments are recently completed and when I went to PUCP, I was able to speak with some of the engineers who had worked on the projects. When asked if there was any improvement in the addition of the geomesh versus the cane reinforcement they found that the two methods seemed to perform to the same standards, and could be used interchangeably depending on the availability of the materials. The second question I had was whether or not there would be an advantage to a hybrid of both the internal cane reinforcement and the geomesh exterior treatment. It was found that the two systems were redundant and there was no significant improvement if both methods are incorporated as compared to the cane or the geomesh methods alone.

Conclusions

In almost thirty years of research on adobe construction done at the PUCP, a great deal has been learned about the behavior of this long-standing construction method. Reliable, simple, and cheap seismic protection techniques have been developed, based on the placement of simple reinforcements. The problem does not lie in the availability of improved construction methods, but rather in convincing the population to adopt these techniques and to use them on their own accord. Rural communities of Peru are extremely poor, and they cannot afford any increase in the cost of their dwellings. They also have very strong traditions and tend to reject suggestions from outsiders, even considering the
In an effort to overcome these perceptions, the PUCP has produced two booklets to educate the Rural Peruvian population about adobe reinforced with cane, and adobe reinforced with geomesh, respectively. Through illustrations and in simple language, the booklet explained the constructive details of reinforced adobe dwellings. Excerpts from these booklets and photos of some of the modules that were used in experimentations can be seen on the following pages, illustrating the extensive opportunities for the improvement of adobe construction without the need for an excessive construction budget.

Figure 30. Illustration of the integration of cane reinforcement into the layers of adobe blocks

Figure 31. Photo of construction of a home using cane reinforcement

Figure 32. Illustration showing mixing of the adobe loam to be used in brick forming

Figure 33. Photo of Camote and his son during a visit to their adobe “Factory”
Figure 34. Illustration showing drying of the formed adobe blocks

Figure 35. Photo of formed adobe blocks drying at Camote’s Factory

Figure 36. Illustration showing corner attachments for wall intersections and corners

Figure 37. Photo of an exposed footing on the experimental modules from a visit to the seismic testing laboratory at PUCP

Figure 38. Illustration showing the attachment method for application of geomesh to the exterior of a new building

Figure 39. Interior photo of window and exposed plastic ties on a module at PUCP
Figure 40. Illustration tying of the geomesh to the exposed plastic ties

Figure 41. Photo of the exterior of one of the testing modules at PUCP showing the attached geomesh

Figure 42. Illustration showing the attachment of the roof structure to the wooden ring beam

Figure 43. Photo of construction of the ring beam and attachment of roof elements

1 Blondet, Adobe in Peru: Tradition Research and Future, 5
2 Blondet, Torrealva, and Villa García, Adobe in Peru: Tradition Research and Future, 3
3 Blondet, Torrealva, and Villa García, Adobe in Peru: Tradition Research and Future, 5
4 Blondet, Torrealva, and Villa García, Adobe in Peru: Tradition Research and Future, 7
5 Blondet, Torrealva, and Vargas-Neumann, Building hygienic and earthquake-resistant adobe houses using Geomesh Reinforcement-Unless otherwise noted, all subsequent illustrations in this chapter come from this publication
6 Blondet, Torrealva, and Villa García, Adobe in Peru: Tradition Research and Future, 6
7 Still Image exported from JICA Housing video
8 Still Image exported from JICA Housing video
Panelized earth and mat housing construction: Precedent Studies at the Universidad Nacional Agraria de La Molina

During a recent visit to Peru, the opportunity was taken to visit the Universidad Nacional Agraria de La Molina (UNLAM) where they were in the process of studying possible adaptations to traditional construction methods to reduce the cost of housing in rural areas of Peru. In this visit, a number of buildings were visited that were built for this study, and a project was presented about a community housing group that is teaching Rural Peruvians how to build these homes.

Figure 44: Photo taken of an Illustration presented explaining the building components and its assembly for the “Casa Tortuga”
“Casa Tortuga” (Turtle House) basic data:

Costs per square meter: $40 (U.S.)- $120 per module, $720 for a house of 6 modules

Materials used: bamboo, woven cane, eucalyptus wood, sand, and concrete

Construction Length: six weeks for a house of 6 modules

Size of each basic module: 3 meters x 3 meters, which is based on the size of the woven cane mats

For the construction of each module in “Casa Tortuga”, frames of eucalyptus wood 3” in diameter are attached to sheets of woven sugar cane mats which come in 3 x 3 meter pieces. Later they are reinforced with additional horizontal and diagonal canes. The roof is created with a similar method; first the 3 x 3 meter frame is constructed, then a skeletal dome is created out of wood, crushed bamboo and wire. On top of this framework sits another woven cane mat. Both the Walls and the roof are finished with multiple coats of mud plaster, and in may cases paint for the finish. Because of its dome shape, the roof of the house resists considerable loads without major deformations. The shape helps transmit the loads to the surrounding walls. The purpose of these houses not to create a building to withstand any seismic stresses, as they were implemented in the mountains, where the seismic risk is lower. The main point of these constructions was to show how a sound and safe building can be built at a very low cost. The design being in modules further reduces the cost, as an inhabitable shelter can be created for $120 then as the family grows or saves more money they can easily add on. The most expensive part of these homes is the concrete slab upon which the structure sits.
Figure 45. Photo of the roof construction of one of these homes at a Rural farm outside of Lima.

Figure 46. Photo of the application of the mud plaster to the outside of the house.
Below are images taken at UNLAM of a building constructed using eucalyptus posts for the main structure. The intention of this building design was to integrate the low cost building materials used in “Casa Tortuga”, with the ease of panelized construction found in the triangulated design of the roof, further reducing the overall cost, and length of construction.

Figure 47. Photo of an administration office at UNALM made with similar construction to “Casa Tortuga”

Figure 48. Photo of the interior of the administration office at UNALM
Chapter Three
History, Location and Analysis of Pisco

Figure 49: Photo taken of Tambo Colorado Ruins in the Ica Province
Macro Location - Peru:

“Somos libres, seámoslo siempre” -“We are free, may we always be so”

The country of Peru covers approximately 1,285,2200 square Kilometers, of which 1.28 sq. km is land and 5,220 sq km is water. Located in Western South America, bordering the South Pacific Ocean, between Chile and Ecuador Peru is slightly smaller than the state of Alaska. Despite its smaller size, the climate in Peru varies from tropical in east to dry desert in west; temperate to frigid in Andes and the terrain ranges from arid western coastal plains (costa), high and rugged Andes further inland (sierra), eastern tropical lowland jungle of Amazon Basin (selva) bordering Colombia and Brazil.  

Peru’s economy reflects its varied geography- abundant mineral resources are found in the mountainous areas, and Peru’s coastal waters provide excellent fishing grounds. However, over dependence on minerals and metals subjects the economy to fluctuations in world prices, and a lack of infrastructure deters
trade and investment. After several years of inconsistent economic performance, the Peruvian economy grew by more than 4% per year during the period 2002-06, with a stable exchange rate and low inflation. Growth jumped to 7.5% in 2007, driven by higher world prices for minerals and metals. Despite the strong macroeconomic performance, underemployment and poverty have stayed persistently high. Growth prospects depend on exports of minerals, textiles, and agricultural products, and by expectations for the Camisea natural gas mega project and for other promising energy projects. Upon taking office, President Garcia announced Sierra Exportadora, a program aimed at promoting economic growth in Peru’s southern and central highlands. 2

With about 28 million inhabitants, Peru is the fourth most populous country in South America as of 2007 with 29.7% of the population between 0-14 years, 64.7% 15-64 years, and 5.6% over 65 years of age. Of this, 45% are Mestizo (mixed Amerindian and white) 37%, white 15%, black, Japanese, Chinese, and other 3%. Religions consist of 81% Roman Catholic, 1.4% Seventh Day Adventist, 0.7% other Christian, and 16.3% unspecified or none. While Spanish is the official language, Quechua is also widely spoken and taught in schools, as well as Aymara, and a large number of minor Amazonian languages.3

The administration of Peru is divided into 25 regions that have their own ‘regional president’ which is the highest level of authority for the area below the presidential approval. The country’s Executive branch consists of President Alan Garcia Perez (since 28 July 2006); First Vice President Luis Giampietri Rojas; and Second Vice President Lourdes Mendoza del Solar (since 28 July 2006); note - the president is both the chief of state and head of government.
Peru is best known as the heart of the Inca empire, but it was home to many diverse indigenous cultures long before the Incas arrived. Although there is evidence of human habitation in Peru as long ago as the eighth millennium BC, there is little evidence of organized village life until about 2500 BC. It was at about this time that climatic changes in the coastal regions prompted Peru’s early inhabitants to move toward the more fertile interior river valleys. For the next 1500 years, Peruvian civilization developed into a number of organized cultures, including the Chavin and the Sechin. The Chavin are best known for their stylized religious iconography, which included striking figurative depictions of various animals (the jaguar in particular) and which exercised considerable influence over the entire coastal region. The Sechin are remembered more for their military hegemony than for their cultural achievement. 

Figure 52. Photo of Chan Chan
The decline of the Chavin and Sechin cultures around the 5th century BC gave rise to a number of distinctive regional cultures. Some of these, including the Saliner and the Paracas, are celebrated for artistic and technological advances such as kiln-fired ceramics and sophisticated weaving techniques. The paracas culture in particular was a Pre-Inca Culture (600 BC - 200 AD) Established on the peninsula of Paracas, influencing the area which is now known as the department of Ica. 

Characterized by their large, underground necropolis where bodies were preserved as mummies wrapped in luxurious cloths and mantles, which were conserved under excellent conditions by the characteristics of the sands of the area. The resulting textile arts are considered as the best of all ancient cultures. Made of vicuña wool or cotton, the patterns are harmonious with many colors, and anthropomorphic and geometric animal designs. While their ceramics did not reach remarkable development, they were influenced by the Chavin culture, and included simple shapes with many colors and illustrations as well as drawings that are similar to the Nazca Culture.
Micro Location - Pisco

The City of Pisco is the Capital of the Province of the same name and is located in the Ica Region of Peru along the south-western coastal desert. The Ica Region has a remarkable geography as it is the only region of the southern coast formed by plains (also called coast plains since the Andean Cordillera is erected inside). Geological folds have determined the formation of lands moving toward the sea which form the Paracas Peninsula as well as determined the Marcona complex, a place where the biggest deposits of iron in the Pacific coast have been formed. Ica’s configuration is due to the geomorphology of its two big and unique fluvial watersheds: the Pisco watershed and Ica watershed. Also, it has an incomplete and continuous current inadequately called Rio Grande because its short waters do not even reach the sea; its waters are mainly used for agriculture in Pampa, Nazca and Ingenio, its final watershed is dry since sand and dried lands absorb its short resources. There are extensive deserts in Ica like the Lancha Pampas before Pozo Santo and Villacuri Pampas which are extremely hot areas. Strong and persistent winds called “Paracas” are present and originate large clouds of sand.
Pisco is around 9 metres (28 feet) and reaches its highest point at 27 meters (89 feet) above sea level. Pisco is bordered by the Pacific Ocean on the west, San Clemente on the North, Tupac Amaru Inca on the East and San Andres to the South. Pisco proper encompasses 24.92 sq km with a population of approximately 54,193 people and a density of 2,174.7 people per sq km.

Originally the village of Pisco was founded in 1640, close to the indigenous emplacement of the same name and stems historically from the Chavin, then Paracas cultures. Pisco originally prospered because of its nearby vineyards and is the namesake of the Peruvian grape liquor, pisco. Today, the area is normally visited because of the concentration of marine animals and birds at the Paracas National Reserve (the “Peruvian Galapagos”). The economy of the area is based on agriculture (mainly grapes and asparagus), wine production, fishing and its derived industry producing fish-flour for exportation, and tourism around the Nazca lines and the Paracas National Reserve.
Climate:

The climate of the coast ranges from warm-semiarid north of 5°S to cool-arid south of 8°S. Despite the proximity to the equator (3°S-18°S), the entire coastal region has a marked annual temperature cycle in response to the direct effects of the sea surface temperature. The warmest period occurs from January through to March and the coolest period from July through to September. Day-night temperature differences increase away from the sea shore.

Figure 56. Average Day-lighting

Figure 57. 24-hour average Temperature
The central and southern coasts (south of 6°S) enjoy a milder climate. Temperature ranges from 8 to 35°C and rainfall is scarce with annual totals below 150 mm. Summer is characterized by warm, moist and sunny conditions with lows between 18 and 22°C and highs between 24 and 30°C. Temperatures over 30°C are commonly observed less than 10 days per year except at the Ica deserts where summer highs can sometimes reach 35°C. Little or no rainfall occurs during the summer. Rare rainfall events are produced by the leftovers of Andean convection and occur during the night. Summer rainfall totals are generally less than 10 mm. Winter is characterized by overcast, cool and damp conditions. Frequent low cloud cover and persistent drizzle events help to keep daytime temperatures cool. Winter highs oscillate between 15 and 23°C and the lows between 8 and 15°C. Several weeks of persistent overcast skies and highs below 19°C are not uncommon between July and September. The so-called ‘rainy season’ develops by late May and comes to an end by mid October. Precipitation occurs in the form of nocturnal-morning drizzle and seasonal totals range between 10 and 150 mm. Winter precipitation favors the development of vegetation over particular coastal mountain ranges known as “Lomas”.

Figure 58. Average annual rainfall
Regulatory Issues- Zoning

The seismic resistant design code of Peru divides the entire country into three regions, assigning peak ground accelerations values which correspond to ground motions with a probability of exceeding 10% in 50 years. The area [Pisco] severely affected by the 15 August 2007 earthquake is classified as Zone 3 which can reach peak ground accelerations of 0.40g (the most dangerous zone). \(^{12}\)

![Peruvian seismic zoning map for design](image)

**Figure 59. Peruvian seismic zoning map for design** \(^{13}\)

![Z-Factors for zone classification](chart)

**Figure 60. Z-Factors for zone classification** \(^{14}\)
According to the National Building Code for Earthquake Resistance, Pisco has been further divided into zones according to seismic effects and associated phenomena like soil liquefactions, slides, tsunamis and others on the area. These zones give information on the possible modifications of the seismic actions due to local conditions and other natural phenomena, as well as limitations and demands that should be considered for the design and building of structures and other projects.

For these Micro-Zones the soil shapes are classified taking into account the ground mechanic properties, the thickness of the stratum, the fundamental vibration period and the propagation velocity of the shear waves.

Zone 1: Shape S1 type: Rock or very rigid soils. This type corresponds to rocky and very rigid soils with shear wave propagation velocities are similar to those defined for a rock, and where the fundamental period for low amplitude vibrations do not exceed 0.25 s, including the cases where there are:

- Whole Rocks or partially altered, with a non confined compressive resistance higher or equal to 500 kPa (5 kg/cm²).
- Dense sandy gravel
- Stratum of no more than 20 m of very rigid cohesive material, with a shear resistance in non-drained conditions higher than 100 kPa (1 kg/cm²), over rock or other material with shear wave velocity similar to a rock.
• Stratum of no more than 20 m of dense sand with N > 30, over rock or other material with a shear wave velocity similar to a rock.

Zone 2: Shape S2 type: Intermediate soils. These are classified as soils with intermediate characteristics between shapes S1 and S3.

Zone 3: Shape S3 type: Flexible soils or stratum with great thickness. This type corresponds to flexible soils or stratum with great thickness where the fundamental period, for low amplitude vibrations, is higher than 0.6s, including those cases where the ground stratum thickness exceeds the following values:

<table>
<thead>
<tr>
<th>Cohesive Soils</th>
<th>Typical Shear Resistance in undrained condition (kPa)</th>
<th>Stratum Thickness(m) (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>&lt; 25</td>
<td>20</td>
</tr>
<tr>
<td>Moderately compact</td>
<td>25 - 50</td>
<td>25</td>
</tr>
<tr>
<td>Compact</td>
<td>50 - 100</td>
<td>40</td>
</tr>
<tr>
<td>Very compact</td>
<td>100 - 200</td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Granular Soils</th>
<th>Typical N values in Standard Penetration Tests (SPT)</th>
<th>Stratum Thickness (m)(*')</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose</td>
<td>4 - 10</td>
<td>40</td>
</tr>
<tr>
<td>Moderately dense</td>
<td>10 - 30</td>
<td>45</td>
</tr>
<tr>
<td>Dense</td>
<td>Bigger than 30</td>
<td>100</td>
</tr>
</tbody>
</table>

(*) Soil with shear wave velocity lower than a rock.

Figure 62. Soil type shear resistance and stratum thickness

Zone 4: Shape S4 Type: Exceptional Conditions. This type corresponds to exceptionally flexible soils and sites where the geological and/or topographical conditions are particularly unfavorable

<table>
<thead>
<tr>
<th>Table N°2</th>
<th>Soil Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>S₁</td>
<td>Rock or very rigid soils</td>
</tr>
<tr>
<td>S₂</td>
<td>Intermediate Soils</td>
</tr>
<tr>
<td>S₃</td>
<td>Flexible Soils or stratum with great thickness</td>
</tr>
<tr>
<td>S₄</td>
<td>Exceptional conditions</td>
</tr>
</tbody>
</table>

(*) The values for $T_p$ and $S$ for this case will be established by a specialist, but in neither case they will be lower than those specified for the shape S₃ type.

Figure 63. Soil Parameters by type
General Building Code Requirements:

According to the National Building code for Earthquake resistant structures, “Every building and each of its components will be designed and built to resist the seismic solicitations determined as specified in the Code. The possible effect of the non-structural elements should be considered in the structural behavior of the Building. Analysis, reinforcement and anchorage detailing will be done according to this consideration.

For regular structures, the analysis will be done considering that the total seismic force acts independently in two orthogonal directions. For irregular structures, it will be assumed that the seismic force occurs in the direction which results most unfavorable for design of each element or component of the study.

The vertical seismic force will be considered to act upon the elements simultaneously with the horizontal seismic force and on the most unfavorable direction for the analysis.

It will not be necessary to consider the effects of earthquake and wind simultaneously. When only one element of the structure, wall or frame resists a force equal to 30% or more of the total horizontal force in any story, it will be designed for 125% of that force.

It will be considered that the seismic behavior of the structures improves when the following conditions are observed:

- Symmetry, for mass distribution and stiffness as well.
- Minimum weight, especially for higher levels.
- Adequate selection and use of construction materials.
- Adequate resistance.
- Continuity in the structure, in plan and elevation.
- Ductility.
- Limited deformation.
• Inclusion of successive resistance lines.
• Consideration of ground local conditions.
• Good constructive practice and strict structural inspection.”

Although there are recommendations in the building code for how to address plan and sectional irregularities in the buildings scheme, as was observed in the case studies, the best approach is to avoid these irregularities all together.

The Site for this project is located in Micro-zone III, (see Fig. 35) and the Building Type falls into Category B ‘Important Facilities’ and is given an importance coefficient of 1.3 (1.5 being the highest) “According to the category of a building and the zone where it is located, it should be planned observing the regularity characteristics and use the structural system indicated in table Nº 7.”

<table>
<thead>
<tr>
<th>TABLE Nº 3 BUILDING CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATEGORY</td>
</tr>
<tr>
<td>A Essential Facilities</td>
</tr>
<tr>
<td>B Important Facilities</td>
</tr>
<tr>
<td>C Common Facilities</td>
</tr>
<tr>
<td>D Minor Facilities</td>
</tr>
</tbody>
</table>
### TABLE Nº 7

**CATEGORY AND STRUCTURE OF BUILDINGS**

<table>
<thead>
<tr>
<th>Building Category</th>
<th>Structural Regularity</th>
<th>Zone</th>
<th>Structural System</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (*) (**)</td>
<td>Regular</td>
<td>3</td>
<td>Steel Reinforced Concrete Walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reinforced or Confined Masonry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dual System</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 and 1</td>
<td>Steel Reinforced Concrete Walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reinforced or Confined Masonry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dual System</td>
</tr>
<tr>
<td>B</td>
<td>Regular or Irregular</td>
<td>3 and 2</td>
<td>Steel Reinforced Concrete Walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Reinforced or Confined Masonry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dual System</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wood</td>
</tr>
<tr>
<td>C</td>
<td>Regular or Irregular</td>
<td>3, 2 and 1</td>
<td>Any system.</td>
</tr>
</tbody>
</table>

**Figure 65. Category and Structure of Buildings**

9. JRC Scientific and technical Reports, 2007 August 15 Magnitude 7.9 Earthquake near the coast of central Peru, 21
12. JRC Scientific and technical Reports, 22
14. Nacional de Normalización, 9
15. Taiki, 6
16. Nacional de Normalización, 10
17. Nacional de Normalización, 10
18. Nacional de Normalización, 11
19. Nacional de Normalización, 12
20. Nacional de Normalización, 17
Chapter Four
Possible Site Selection & Preliminary Programming Issues

Figure 66: Photo of final site location chosen for the project
Overall Use Issues

Due to the Lower Economic Level as well as the recent devastation of the Residents in Pisco, the budget is much lower than that of a contemporary home (in very general terms, the cost needs to be around 1/3 of the cost of an “affordable home” in the US). This keeps the program to a minimum and, averages 800- 1,200 s.f. per unit. The idea is to have each home meet the minimum necessary requirements for a typical family, and maintain the structural integrity of the dwelling units. There will be a small amount of individual outdoor program, but the clustering of the units will allow for a more open outdoor feel. Based on preliminary studies, in the town center there is a greater density, and the housing cluster could be organized around attached party walls which may
lead to increased stability. Further from the center and towards the beach, the homes seem to become detached single family homes, while maintaining a fairly high density. As the site is yet to be determined, I am proposing two cluster options for each of these conditions, and to be later decided based upon their tested seismic stability.

Figure 68. Pisco Peru, Site possibility #1 by Plaza Mayor

Figure 69. Pisco Peru, Site possibility #2 Near Beach
Because the climate in Pisco has very little rain, in consideration for further expansion, it can be assumed that this will occur vertically, as the roofs can be flat, and built in such a way to become another floor in the future. Depending on the final site decisions, setbacks will be consistent with those of the surrounding blocks. Generally speaking, in area #1 (town center), there will be little to no setbacks on the front and sides, as they will be sharing party walls. In area #2 (closer to beach), there may be minimal front setbacks as well as a small separation (5-10ft) between units. Either site will remain within the existing block structure already established in the town of Pisco and will need to be appropriately connected with municipal utilities. Due to the lack of rain in Pisco, it is highly unlikely that there will be any rainwater collection, however there is a possibility for grey water re-use, and trash decomposition on site to aid in small scale landscaping/gardening on site. The nature of adobe construction lends itself well to passive heating and cooling in the desert-like climate of Pisco, so there will be special attention paid to maintaining the thermal mass of the building. If done properly, this thermal mass can also potentially lead to the increased seismic stability of the building. Although there are assumed to be municipal utilities, in an effort to keep the operating cost of the homes as low as possible, special attention will be paid to proper day lighting of all of the internal spaces.
Site Issues

In area #2 there will be a greater amount in green space allocated to the individual dwelling units given the side and front yard setbacks. In both options there will be a communal outdoor gathering space to give additional area for gardening and grey water retainage, and waste decomposition. There is also a need in both situations for an outdoor laundry hanging area, which may be considered in part of the community outdoor space. In area #1, while there will not be private side yard areas for each dwelling unit, there will be separation within the community outdoor space in order to define the semi private and public outdoor uses. Vehicular accommodations will be front- loading on site #2 or possibly in the form of a side/ back loading parking court for site #1. In both instances, there will only be consideration for 1 car per unit as it is rare that there is more than 1 car per family in Peru. It should also be noted that while a parking area will be provided, it will not necessarily be covered or a part of a garage as the most commonly found parking conditions in Lima are to have the car pull up within the gate of the yard.

While there is no specific requirement for accessory structures at this point, it is possible that there could be a common laundry area that is within the outdoor community space that is not attached to any of the dwelling units.
Unit Room Program List & Adjacency Diagrams

**Adjacency Diagram Unit Type #1**

![Diagram of Unit Type #1](image)

Figure 70. Spatial relationship diagram of rooms in Unit Type #1

<table>
<thead>
<tr>
<th>No. of Units</th>
<th>Description</th>
<th>Square Footage</th>
<th>No. of occupants:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Bedroom</td>
<td>150 s.f.</td>
<td>1-2</td>
</tr>
<tr>
<td>1</td>
<td>Master Bedroom</td>
<td>175 s.f.</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Master Closet</td>
<td>30 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Closet</td>
<td>16 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Bathroom</td>
<td>40 s.f.</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Service Area (Bedroom)</td>
<td>100 s.f.</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Service Area (Bathroom)</td>
<td>40 s.f.</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Kitchen</td>
<td>100 s.f.</td>
<td>2-4</td>
</tr>
<tr>
<td>1</td>
<td>Living/ Dining</td>
<td>200 s.f.</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>Laundry</td>
<td>50 s.f.</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1. Programmed rooms and Square footages for Unit Type #1

**Adjacency Diagram Unit Type #2**

![Diagram of Unit Type #2](image)

Figure 71. Spatial relationship diagram of rooms in Unit Type #2

<table>
<thead>
<tr>
<th>No. of Units</th>
<th>Description</th>
<th>Square Footage</th>
<th>No. of occupants:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Bedroom</td>
<td>150 s.f.</td>
<td>1-2</td>
</tr>
<tr>
<td>1</td>
<td>Master Bedroom</td>
<td>175 s.f.</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Master Closet</td>
<td>30 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Closet</td>
<td>16 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Bathroom</td>
<td>40 s.f.</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Kitchen</td>
<td>100 s.f.</td>
<td>2-4</td>
</tr>
<tr>
<td>1</td>
<td>Living/ Dining</td>
<td>200 s.f.</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>Laundry</td>
<td>50 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Office</td>
<td>60 s.f.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Programmed rooms and Square footages for Unit Type #2
Figure 72. Spatial relationship diagram of rooms in Unit Type #3

Table 3. Programmed rooms and Square footages for Unit Type #3

<table>
<thead>
<tr>
<th>No. of Units</th>
<th>Description</th>
<th>Square Footage</th>
<th>No. of occupants:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Bedroom</td>
<td>150 s.f.</td>
<td>1-2</td>
</tr>
<tr>
<td>1</td>
<td>Master Bedroom</td>
<td>175 s.f.</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>Master Closet</td>
<td>30 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Closet</td>
<td>18 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Bathroom</td>
<td>40 s.f.</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Kitchen</td>
<td>100 s.f.</td>
<td>2-4</td>
</tr>
<tr>
<td>1</td>
<td>Living/Dining</td>
<td>200 s.f.</td>
<td>4</td>
</tr>
</tbody>
</table>

Cluster Adjacency Diagrams

Figure 73. Spatial relationship diagram for overall cluster organization Type #1
Figure 74. Spatial relationship diagram for overall cluster organization Type #2

Figure 75. Spatial relationship diagram for overall cluster organization Type #3
Figure 76. Spatial relationship diagram for overall cluster organization Type #4
Chapter Five
Site Visit and Architectural Analysis

Figure 77. Photo of the Church existing on site prior to the earthquake
Figure 78. Site Location and surrounding conditions in Pisco
Figure 79. Site Location and Appropriate solar orientation
Figure 80. Figure- Ground conditions surrounding site Before Earthquake
Figure 81. Figure- Ground conditions surrounding site After Earthquake
Land Use Diagram

- Commercial
- Residential
- Mixed Use
- Civic/
- Religious

Figure 82. Land use diagram of area surrounding site (Pre-Earthquake)
Figure 83. Population density and common Gathering areas (Pre-Earthquake)
Figure 84. Pedestrian and Vehicular traffic flow- Points of interest
Figure 85. Significant Views into and out of Site
Chapter Six
Education Facility Programming

Sustainable Education Facilities

Energy Production
- Animal Pen
- Biodigester
- Generator
- Gas Storage

Waste Water Treatment (From all Facility Bathrooms/Kitchen)
- Settling Tank
- Filtering Marsh
- Garden

Figure 86. Early Diagram Showing integration of sustainable education facilities
Programmed Facility Spaces:

<table>
<thead>
<tr>
<th>Function</th>
<th>Sub-function</th>
<th>Number</th>
<th>Area (S.F.)</th>
<th>Occupants</th>
<th>NSF Total</th>
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</thead>
<tbody>
<tr>
<td>Classroom(s)</td>
<td></td>
<td>8</td>
<td>640</td>
<td>32</td>
<td>5120</td>
</tr>
<tr>
<td>Conference Room/ Pres.</td>
<td></td>
<td>4</td>
<td>480</td>
<td>18</td>
<td>1920</td>
</tr>
<tr>
<td>Clinic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>460</td>
</tr>
<tr>
<td></td>
<td>nurse station</td>
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<td>160</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>Exam</td>
<td>1</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Waiting room</td>
<td>1</td>
<td>200</td>
<td>6</td>
<td>200</td>
</tr>
<tr>
<td>Bathroom (ADA)</td>
<td>Male &amp; Female</td>
<td>1 ea.</td>
<td>50</td>
<td>1 ea.</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Office/ Admin.</td>
<td>2</td>
<td>120</td>
<td>1 ea.</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>Equip. Storage</td>
<td>1</td>
<td>150</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>490</td>
</tr>
<tr>
<td>Cafeteria</td>
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<td></td>
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<td></td>
<td>950</td>
</tr>
<tr>
<td>Dining</td>
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<td>1000</td>
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<td></td>
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<td>1</td>
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</tr>
<tr>
<td>Storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Freezer</td>
<td>1</td>
<td>75</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Cooler</td>
<td>1</td>
<td>75</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Dry Storage</td>
<td>1</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Housing Units</td>
<td></td>
<td>15</td>
<td></td>
<td></td>
<td>550</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8250</td>
</tr>
<tr>
<td>Bedroom</td>
<td></td>
<td>2</td>
<td>150</td>
<td></td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>150</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Living</td>
<td></td>
<td>1</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Bathroom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Church Reconstruction</td>
<td>Chapel</td>
<td>1</td>
<td>3000</td>
<td>150</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>Bathroom (ADA)</td>
<td>Male &amp; Female</td>
<td>1 ea.</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Office/ Admin.</td>
<td>2</td>
<td>120</td>
<td>1 ea.</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>Equip. Storage</td>
<td>1</td>
<td>150</td>
<td></td>
<td>150</td>
</tr>
<tr>
<td>Library</td>
<td>Reading Area &amp; Stacks</td>
<td>1</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Reception/ Checkout</td>
<td>1</td>
<td>100</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Work Room &amp; Office</td>
<td>1</td>
<td>200</td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Gallery</td>
<td></td>
<td>1</td>
<td>2000</td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>Materials Store</td>
<td>Checkout area</td>
<td>1</td>
<td>300</td>
<td></td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Supply Display</td>
<td>1</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>Exterior Spaces:</td>
<td>Memorial Plaza</td>
<td>1</td>
<td>6000</td>
<td></td>
<td>6000</td>
</tr>
<tr>
<td></td>
<td>Courtyard(s)</td>
<td>1</td>
<td>3000</td>
<td></td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td>Playground</td>
<td>1</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Construction Yard</td>
<td>1</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td>Waste Water Treatment</td>
<td>Settling Tank</td>
<td>1</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Filtering Marsh</td>
<td>1</td>
<td>1000</td>
<td></td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Garden</td>
<td>1</td>
<td>3000</td>
<td></td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>Total SF Required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>42,600</td>
</tr>
</tbody>
</table>

Table 4. Building Program Square footages and uses
Figure 87. Adjacency diagrams showing relationships between the major program components, and the adjacent street edges.
Overall Use Issues

After visiting the town of Pisco, and talking with professors at the Pontificia Universidad Católica de Peru, I discovered that there was a huge disconnect between the known and tested construction method, and the actual construction of the average home in the area. It seems that there is not as much of a question as to how to build with adobe to withstand earthquakes, as why people are not following the methods that have been shown to work. Although I feel there is still a bit of room for research as far as how formal qualities can improve the seismic stability of the houses, the problem in Pisco seems to be more an issue of lack of education. After the earthquake, most of the residents of the area lost their trust in the strength of adobe construction, but since they do not have ample funds (block construction costs average 3 times as much as adobe) to buy the materials necessary for masonry construction, almost a year later they are still living in the same conditions they were the week after the earthquake. Another notable educational issue is that while a majority of the buildings that were destroyed were made out of adobe, many of the masonry buildings also failed due to a lack of proper construction methods.

Beyond the necessity to teach earthquake victims how to properly re-build, I feel there is also a need to revive the earth building tradition in general, for both the economic and sustainable aspects. While the most obvious issue that needs to be addressed is the durability of earth construction, there are other issues associated with earth construction that has led to a negative stigma, and as people have more funds they tend to move away from earth construction techniques and to concrete construction. There seems to be an “all or nothing” mentality when it comes to used construction techniques. This issue should also
be addressed with this new education facility, there should be a range of earth construction techniques demonstrated that show the many ways that it can be used, from the high end down to the affordable spectrum, showing that there are many different advantages to earth construction that should not be overlooked when the construction budget increases.

With this lack of sufficient construction education in mind, I feel that programmatically, the most beneficial building that can serve Pisco is an Earth Building Education center in the heart of the city which can serve as a shelter for the displaced while the town is being re-built. Upon visiting the town I have chosen a Site two blocks east of the Plaza de Armas, on a direct axis from the park between the Cathedral and main Municipal building. This site was the former home to the Iglesia de la Compañía, which was destroyed in the earthquake. In addition to the church, a former health clinic and some mixed use residential buildings formerly resided at the site. It is my intention to rebuild the church facility and in conjunction with the neighboring lots, add to it the education facility and housing areas. With these varying uses in mind, I hope to build a facility that provides temporary housing for those in need, with the future use being focused on Education of Earth building techniques.

Because the climate in Pisco has very little rain, in consideration for further expansion, it can be assumed that this will occur vertically, as the roofs can be flat, and built in such a way to become another floor in the future. Setbacks will be consistent with those of the surrounding blocks. Generally speaking there will be little to no setbacks on the front and sides, and will remain within the existing block structure already established in the town of Pisco and will need to be appropriately connected with municipal utilities. Due to the lack of rain in
Pisco, it is highly unlikely that there will be any rainwater collection, however there is a possibility for grey water re-use, and trash decomposition on site to aid in small scale landscaping/ gardening on site. The nature of adobe construction lends itself well to passive heating and cooling in the desert-like climate of Pisco, so there will be special attention paid to maintaining the thermal mass of the residential program areas. If done properly, this thermal mass can also potentially lead to the increased seismic stability of the building. Although there are assumed to be municipal utilities, in an effort to keep the operating cost of the facility as low as possible, special attention will be paid to proper day lighting of all of the internal spaces.

In an effort to relate the Facility to the existing surroundings as much as possible, the street frontage will be respected, while allowing small setback yards in order to provide glimpses into the site and the activities held within.

Figure 88. Conceptual diagram showing how the Education facilities portion of the program can be used to create a threshold between the private living quarters and the public community facilities.
While the program of the education facility is clearly centered around providing adequate areas for hands on educational workshops and storage, the outdoor spaces are very important as well. The outdoor spaces will first and foremost provide the construction yard spaces, but in addition they serve as transitional spaces, flittering between the public, semiprivate, and private spaces. These areas also supply an activated point of interest within the site that allows passers-by the opportunity to see what goes on in the Facility, and perhaps bring them back to participate. By pulling these elements off the street edge a significant point has been placed, giving importance to its presence and the activities that take place within. By programming the spaces as one would a plaza, they become educational public parks that facilitate everyone in Pisco, even if they are not affiliated with the projects.

**Outdoor Spaces:**
Privacy Gradient

*Figure 89. Organization of outdoor spaces to improve Privacy gradient*
Design Program- Problems, Goals and Objectives

“If we are to prevent new calamities, the profession shall have to amend its practices. From the start of professional training a student must be made conscious of the need to see structure as an integral part of the project and not as some nuisance that the structural designer adds to the architectural project- they must not be viewed as mere add-ons”. Christopher Arnold [1].

Problems

The Disadvantages (and some misconceptions):

1. Structural issues- They have poor binding force- decreased seismic resistance
2. Can have low compressive strength
3. Durability issues- shrinking, cracking, rotting, erosion, etc.
4. Loam construction is not water resistant
5. There are pest problems (bugs, rodents)
6. Standardization Issues- Earth/ Loam is not a building material
7. Lengthy (although simple) construction process- curing of bricks and finished walls
8. Buildings are difficult to clean and Maintain
9. Compliance with building codes can be difficult
10. Aesthetically distinct and perceived to be inferior to contemporary construction methods
The Advantages

1. Earth construction balances air humidity
2. Thermal mass of Earth construction balances indoor air temperatures throughout the day
3. Saves energy costs and reduces environmental pollution
4. Lower embodied energy of material at comparable construction energy costs when compared with concrete construction
5. Always a reusable construction material
6. Lower material transportation cost (found on site)
7. Ideal for “do-it-yourself” construction- easy to do
8. Loam absorbs air pollutants

Goals and Objectives

1. Structural Issues
   
   By adhering to the set of rules established in the case studies, the building’s structure can be integrated into the design, and new ways the buildings design can be informed by the construction method chosen for each element.

2. Durability Issues
   
   The main causes of deterioration to an earthen building in conjunction with time have to do with shrinking, cracking, erosion, and mechanical damage due mainly to water issues. As evidenced in the previous case studies, Although the material itself is the main cause for these issues, with proper architectural detailing such as reducing wall roughness, increasing overhangs, stabilizing earth with additives, and applying surface treatments to seal the structure, the tendency for deterioration are greatly reduced.
3. Standardization/ Reduction of Construction Time:

While there are many possible techniques that can be applied to increase the structural stability, durability and aesthetics of earth construction, there are still formidable issues related to implementation of standardized construction practices to ensure that buildings are constructed properly and consistently to guarantee their performance. While in theory, the majority of the materials for earth construction are found on site keeping costs low, there are still concerns relative to the time expended in traditional adobe block construction. The process itself is relatively simple, however to ensure proper construction with limited shrinkage, suitable durability and the like, the curing times needed for both the brick making and the curing of the completed walls can be quite intensive. There are again many approaches to be taken with this issue from varying the type of earth construction (rammed earth, adobe bricks, fabric and wet loam) to using mechanization for the construction of bricks. Because each of these methods has advantages and disadvantages they will be used to represent the varying hierarchies in the facilities program.

It is shown that generally speaking, as the amount of labor needed decreases, the cost of materials increases. With this in mind, the most basic program elements of the living facilities will be built out of the reinforced adobe construction, demonstrating the simplest and most economical improvements the average homeowner can implement in their home as they are rebuilding from the earthquake. As the functions increase in inhabitants and importance, the earth construction method respectively increase in refinement and the less cost effective and more innovative approaches to earth construction will be explored.
Chapter Seven
Initial Schematic Design

Figure 90. Photo Facing site taken after the Earthquake
Addressing the Existing Context

While the intention of the project is to create a campus that encourages community interaction by way of education, the density of the existing surroundings must be taken into consideration so as to create an unobtrusive facility. Given the surrounding housing mixed use typologies as were seen in the site analysis figure ground, analysis of the sectional qualities of such spaces can be strong influencing factor for the final design of the construction facility.

![Figure 91. Sketch showing the pre-earthquake sectional qualities through the main plaza, the cathedral block, and the proposed site block.](image1)

![Figure 92. Sketch showing the pre-earthquake sectional qualities the plaza and commercial center one block south of the site.](image2)

Of considerable importance when discussing the surrounding conditions is the defining street edge found in both highly commercial and highly residential areas. The resulting street wall clearly delineates the public street edge from the privately owned residences or businesses. In the case of a commercial building, while the facade comes up to the edge of the sidewalk, the materiality is generally transparent (windows) or openable during business hours.
Common in most residential contexts is a defining barrier on the sidewalk edge, delineating the private space, yet retaining consistency with the rest of the towns’ context. In many cases there is a wall that creates a private outdoor entry space prior to the actual front door. In the situation of a residence that is also home to a bodega or small restaurant, the enclosed structure will almost always come up to the sidewalk edge, with the commercial portion on the first floor street edge, and the residential portion of the building will be on the back and upper stories on the home. There also exist many typologies where the entrance and built structure of a residence will sit on the sidewalk edge, and there will be a central courtyard further inside the home. Regardless of residential or commercial use, the overall lack of building setbacks in both settings is a crucial observation, as when this pattern is broken, the activity or programming of the resulting spaces command hierarchy and importance in comparison to the surroundings.

Figure 93. Sketch showing the pre-earthquake sectional qualities of a typical residential neighborhood

Figure 94. General Organizational Diagram of how the Program is as a gradient between the public street edge and the private residential spaces
Designing to maintain the street edge while creating a sense of refuge

Massing relationship A

The first possible site arrangement maintains the existing chapel plaza, and uses this condition to create a main entrance giving importance to the space.

Figure 95. Diagrammatic aerial showing the solid street edge created by the new buildings with 1 entrance off the existing plaza

Figure 96. Perspective showing the street level conditions that would be created with the massing of possibility A

While this option is clearly successful at fitting in with the context, issues arise with the disconnection between the community and the activities taking place within the facility
Massing relationship B

In option B, additional entries are created on the east side of the block as well as one mid-block. With these additional, smaller entrances, the street edge is again maintained, but a more inviting condition is created for those walking by.

Figure 97. Diagrammatic aerial showing the maintained street edge with additional entries mid-block and at the east

Figure 98. Perspective showing the street level conditions that would be created with massing of possibility B

In this situation the level of transparency is greatly improved so that the community can have a better idea of the activities within the facility however a greater intervention may be needed to become more welcoming.
Massing relationship C

In option C, the previously proposed entrances are enlarged to create actual breaks in the building mass along the street edge, as well as shifting the building on the plaza further to the north street to make its entry into an opening as well.

Figure 99. Diagrammatic aerial showing breaking down of the street edge to create more entry at a larger scale

Figure 100. Perspective showing the street level conditions that would be created with the massing of possibility C

In this final proposal, a much more inviting street condition is created that allows pedestrians to come into the site and observe or experience part of the activities going on within the school as opposed to only providing a line of sight.
Massing relationship D

In option D, the internal functional activities taking place in the construction yard are intended to be brought to the street realm through alignment of the larger entries on the main street.

Figure 101. Diagrammatic aerial showing how the openings along the main road can be used to draw people into the activities of the construction yard.

Figure 102. Diagrammatic aerial showing the centralization of the construction yard within the block. As with the enlarged entries found in option C, in this scenario the internal connection with the street is improved when the buildings are used to frame the views of the construction yard and again creates a more open, welcoming entry.
Massing relationship E

In this final proposal, the overall maintenance of the street edge with selective openings is used to create pockets of private areas consistent with the more traditional courtyard typologies.

*Figure 103. Diagrammatic aerial showing how maintaining the street edge allows for private areas within the residential area.*

*Figure 104. Diagrammatic aerial showing the privatization of the residential area.*

By using the educational facilities as a buffer to the residential facilities, the buildings can remain a part of the campus as a whole, but a more traditional residential organization is achieved, defining the private areas of the program.
Preliminary Site Design

Based on the Massing relationships found in options D and E, this proposal attempts to optimize the openings on the street edge that allow for the residents of Pisco to feel welcome and invited into the education facility regardless of their enrolment in the programs offered. The importance of this scheme lies in the ability to maintain openness to the public realm while keeping the street edge relatable to the exiting context of the city. In an effort to achieve this consistency, the residential portion of the program has been placed on the east side of the site block, corresponding to the surrounding smaller scale residences of the city. The administrative portions of the education facility have been located on the north side attempting to correspond with the heavier commercial activity on the main street. The completely public portion of the program, the church reconstruction remains in the same position of the church before it was destroyed by the earthquake. The positioning not only allows the new building to function as a memorial, but also helps to define the beginning of the school programming. While there are no closed entrances off the plaza.
or the main street, the internal instruction area still needs definition in order to maintain the effectiveness of the educational activities taking place within. Finally, the classroom portion of the campus is located on the southernmost area of the site. By doing this the classrooms are not necessarily distracted or interrupted by what is taking place in the street realm, yet it is still visible to these areas. Additionally by setting the construction yard and classrooms back, there is increased security for any equipment that may be used, as well as keeping passers-by from getting hurt by accidentally walking through these spaces.

Figure 106. Diagrammatic aerial showing the preliminary design with a centralized construction yard, main entry off the memorial plaza, and secondary entrances off the main street.
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<thead>
<tr>
<th>Phase I</th>
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<td>Office/ Admin.</td>
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<td>Equip. Storage</td>
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<td>Playground</td>
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<tr>
<td>Construction Yard</td>
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Table 5. Phasing of the final construction and the programed spatial requirements of each area
As this project is proposing a campus-like set up of multiple buildings all with different construction techniques, there is a need for an organizational phasing to keep the project running as planned while at the same time serving as an educational tool for the construction process. With this in mind a five phase organization has been established, beginning with the most basic construction methods and progressing into the more advanced methods as the participants’ construction skills improve. While the final outcome of this project is a hands-on earth construction school, the inception of the project is intended to address the more immediate need of disaster relief housing for the residents of Pisco.

Figure 107. Aerial view of the completed Phase I Residential units (in white)
Figure 108. Aerial view of the completed Phase II preliminary education facilities

Figure 109. Aerial view of the completed Phase III Secondary education facilities (classrooms)
Figure 110. Aerial view of the completed Phase IV Gallery and Library

Figure 111. Conceptual Perspective of the Completed Phase V Church Reconstruction
Figure 112. Completed Scheme Phase V - Preliminary Site plan showing the varying phases and program areas within the site block
Chapter Eight

Phase I Adobe Block Housing Design

Figure 113. Plan showing location of Phase one within site in pink
Phase I Residential Housing Construction

Based on research done at the Pontificia Universidad Catolica de Peru, the previously studied bamboo reinforcement of traditional adobe construction was applied to the design of the residence halls. Using those principles, an adaptation on corner connections was established to improve the overall attachment of structural elements throughout the home. These fastening blocks can also be used within the walls to attach other built elements, further tying the structure together. The final block dimensions were established based on common intervals for seats, stairs, counters, etc. The resulting module is 15" x 15" x 3.75" tall. Based on these dimensions, a variety of built in furniture and structural attachments can be achieved. Common implementations may include; two blocks attach a stair, 4 creates a seat, 8 reaches a standard table height, and 9 blocks can be used as a base for a standard kitchen counter.

Figure 114 & 115. Conceptual illustrations of the corner reinforcement strategy
Figure 116. Drawings of the existing block modules common to adobe home construction in Peru, and the dimensions of the proposed block sizes for the new attachment strategies.

Figure 117. Diagram of possible implementation of the proposed block module attachment strategies.
As discussed in chapter XX when designing the plan of a building in an earthquake prone area, importance is placed on the overall symmetry of the buildings design. As shown, the house plan is a simple layout in order to increase the ability of the building to stabilize as an integrated unit in the event of an earthquake. In addition to the symmetry of the plan, care was taken to assure that the residential buildings were appropriately day lighted during the hours they are in use. In General, the houses are occupied in the mornings from about 6 a.m.- 9 a.m., and in the evenings from 4 p.m. - 8 p.m., plus overnight hours. Given this information, it was important to design the house to let in the most amount of light during these hours. Along with the consideration for orientation, it is important to note that because of the arid desert climates, the size and

Figure 118. First and Second Floor House plans showing layout and overall symmetry of plan shape
placement of openings is critical when trying to take advantage of the buildings thermal mass. Because it is quite hot during the day and can be fairly cool at night, the best design considerations for passive heating and cooling is to allow for thick walls with small openings relatively high up the walls. These fenestrations allow the hot air to rise and escape, while reducing the amount of intense sunlight that floods the building during the day. Because of the sun’s strength in these climates, ample day-lighting can be provided with smaller, properly oriented windows. Along with these design elements, there are positive implications for warming the homes at night. Because of the mass of the houses walls, heat is stored within during the day, and this warms the house throughout the night.

Figure 119. Diagram of the daylight infiltration to the home during the occupied hours of the morning
In the previously discussed adobe block module, there are also important structural connections that can be made using the same technique. By having the bamboo reinforced corners, the floor and roof systems can be constructed independently while still being tied into the house structure. As can be see above and in figure xx, the floors and roofs are built upon an independent post and beam system. The advantage to this type of construction is that in the event of an earthquake when there are both horizontal and vertical stresses affecting the building, the horizontal and vertical loads of the structure can react independently. If for example, part of a wall collapses, because the floor above is on its own system, it can remain intact, reducing the risk of a total building collapse.
Figure 121. Rendered corner section showing construction details from the foundation and floor elements, through the second floor, and the roof attachments.
Images of the Final House Design

Figure 122. Birds eye view of completed individual house showing its relationship to the street edge

Figure 123. East Elevation of a housing cluster within the site context
Figure 124. Transverse section through house

Figure 125. Longitudinal section through house
Figure 126. Photo of final Housing Section Model, View from street corner

Figure 127. Photo of Final Section Model, view from interior
Figure 128. Photo of Final Housing Section Model, view of stairway and kitchen showing elements attached via new block typology
Housing construction pamphlet

While this project is the creation of a hands on earth construction education facility, there is a high likelihood that there will be residents of Pisco and the surrounding region that will be unable to attend the school. For these people, a manual of appropriate construction is needed so that the information and innovations discussed at the school can be available to anyone that would like to build their own building, regardless of their ability to attend classes. For these people, a graphic handbook was created that illustrates the construction methods for each phase of the education facility and the resulting buildings. The basic construction methods for the foundation preparation and housing typology can be seen below, and the instructions for the other buildings will be seen in the subsequent phasing chapters.

Preparing the Site

![Figure 129. Illustration showing the layout of the building on the site](image)
Clean and level the area where the Building will be built, then following the plan, layout the location of the walls with strings and chalk.
Dig a continuous ditch at least 15” deep, that these ditches will be used to raise the base of the wall above the soil and ensure that the Building is set on a firm and stable Foundation.

Fill half of the foundation trench with this concrete mixture.
Set the boards for the above ground plinth wall around the edges of the ditch as shown, they should be at least 5” above the ground level. Then place large stones on top, creating a foundation that is composed of more stones than concrete mixture—increasing its compressive strength. Finish with another layer of concrete.

Figure 132. Illustration showing the addition of stones to the concrete footings

Figure 133. Illustration showing the framework for the above ground portion of the footing

Set the boards for the above ground plinth wall around the edges of the ditch as shown, they should be at least 15” above the ground level.
Fill the framework with the same stone and cement mixture used for the foundation making sure the Reinforcement (bamboo) is adequately surrounded.
Prior to filling the continuous footing, set the 6” x 6” posts into the pile holes. Once set, replace the soil that was removed and compact the area by ramming.

For the House Foundation, in addition to the 15” continuous footing, dig piles at the corners at least 30% of the depth of total wall height (6’ for a 20’ house).
The next step is to set the bamboo reinforcing members into the ditch 45" apart (3 adobe bricks) and at corners or intersections of walls.

After sealing the plinth with a layer of mud-straw mortar, begin laying the first layer of adobe bricks. In corners or where walls meet at 90°, the first layer consists of full single bricks (half bricks if necessary).
The second layer starts with a corner composite block with exposed bamboo tie-ins, and the length of the wall continues with standard bricks. The corners should now meet and surround the 6" x 6" reinforcing posts. Once the walls have been set, the corner bamboo ties can be attached.
Chapter Nine

Phase II Recycled Tire Classroom Construction

Figure 143. Plan showing location of Phase two within site in pink
Phase II Classroom Construction

Phase two of the Earth Construction Education Facility consists of the erection of the classroom pods and construction yard. Based on the educational structure of the program, the methods used are meant to progress from the most familiar and basic techniques to the most advanced and innovative. While the construction of phase two may be considered easier, or less technical, this method is not necessarily something that is familiar to the residents of Pisco. Despite its unfamiliarity, the idea behind the design is to demonstrate how recycled elements can be incorporated into a building in order to reduce the cost of construction and expedite the owners ability to afford to rebuild their homes. The idea of using recycled tires to build a structure was first introduced to the project after doing a precedent study of buildings by the Rural Studio from the Auburn University in Alabama.

In this study the Shiles house (2002) and Yancey Chapel (1995) were researched for their ease of construction as well as the structural and potential for appropriate shelter. In these designs, Architecture students built the recycled tire walls by first stacking the tires, then packed with earth. The system is held together with chicken wire and finished with a layer of cement.
In the design of the classroom pod, the tire construction method is used in conjunction with the panelized mat and earth method previously discussed in the “Casa Tortuga” project done at the Universidad Nacional Agraria de La Molina. Combining these two techniques with a rammed earth knee wall, the classrooms can be rapidly constructed, while at the same time introducing new techniques into the educational program of the school. By introducing the use of rammed earth at this early stage, there is also an opportunity for the construction students to become familiar with the methods, as there are full buildings constructed with rammed earth in later phases.

Figure 146. Localized plan of the classrooms and construction yard

The plan of the classroom pods themselves are quite simple, meant to be an open air, three sided structure so that there is a direct interaction with the construction yard in the middle.
As shown in the above rendering, the side walls of the classroom pods are made of the recycled tire method, while the back wall begins with a rammed earth knee wall, and is finished with two adobe covered cane mat panels. The plan and organization of the classrooms is intended to delineate the space designated to each individual class, giving them a solid wall for presentation purposes, while remaining relatively open to the rest of the construction yard. The openness not only keeps the classrooms cool and sheltered from the hot sun, but also allows the students to observe the activities of the other classes, as the educational program is set up in a progressive manner in which each class
builds upon the techniques developed in the previous class, and many of the educational activities will take place in the construction yard in the center of this area.

Figure 148. Detailed section of the construction of the tire wall and foundation

1 Andrea Oppenheimer Dean, and Timothy Hursley, Rural Studio: Samuel Mockbee and an Architecture of Decency (New York: Princeton Architectural Press, 2002), 96
2 Dean, Andrea Oppenheimer and Timothy Hursley, Proceed and Be Bold: Rural Studio After Samuel Mockbee (New York: Princeton
Figure 149. Section showing the relationship of the classrooms to the depressed construction yard. This arrangement allows for a separation between the two elements while preserving a clear line of sight from the classrooms to the yard.
Figure 150. Rendering of the preliminary design of the classroom pods

Figure 151. Perspective looking at the activities in the construction yard from within a classroom.
Figure 152. Photo of Final Classroom Section Model, view from the construction yard

Figure 153. Photo of the Final Classroom Section Model, Side view into class.
Figure 154 & 155. Pamphlet illustration showing the filling of the tires with earth

Figure 156. Illustration showing a person checking that the wall has been laid level
Figure 157. Illustration showing a stacked tire wall and a possible layout

Figure 158. Illustration of the placing of chicken wire over tires to hold the system in place

Figure 159. Illustration of how to apply the finish of adobe mud to the wall
Figure 160. Plan showing location of Phase three dining hall within site in pink
Phase III Dining Hall Construction

Phase three of the campus construction consists of two buildings, the first, the Dining Hall, will be discussed in this chapter. The construction technique for this building is based on various research done about bamboo reinforcement for rammed earth. A great deal of research was done on this topic by the Building Research Laboratory at the University of Kassel, Germany where they developed a rammed earth wall technique that used bamboo reinforcing for seismic stability. In a project conducted jointly with the Francisco Marroquin University and the Center for appropriate technology (Guatemala),¹ “80 cm wide and one story high bamboo reinforced rammed earth elements were constructed using a T-shaped metal formwork.”² This method is meant to be able to direct seismic deformation along the joints in the rammed earth panels which act as pre-designed failure joints.

![Figure 161 & 162. Section (left) and axonometric (right) of the earthquake-resistant low cost housing prototype developed by the BRL in Guatemala 1978.](image-url)
A built example a similar construction system can be seen in the San Francisco Xavier Residence, in Brazil by Architect Maxim Bucaretchi. This home was built entirely of local building materials, and the majority of the stone, bamboo, timber, and earth was taken directly from the site. The Xavier residence was built using a bamboo reinforced system where the rammed earth wall elements are formed in L and U-shapes which stabilize themselves by their shapes. These wall elements are separated by what are essentially “break-away” adobe block walls.

Figure 163. Photo of the Completed Xavier residence.

Figure 164 photo of the Xavier residence wall panels under construction.
Based on these systems the dining hall is constructed beginning with the rammed earth buttressing walls that will eventually run perpendicular to the main wall and be the separation joints for the subsequent bamboo reinforced wall panels. This design has a twofold benefit, first, in the beginning stages of the construction school, the buttressing portion of the building can be made, and serve as practice to improve their rammed earth technique. During this same time, the area between the buttresses can be filled (as they will be in the final design) and serve as seats in the interim, defining the area of the site as well as creating an area of refuge or gathering.

Figure 165. Rendered corner showing the basic building elements of the dining hall including the buttress walls, and the in-fill walls.
Figure 166. Floor Plan of Dining Hall and Kitchen Building with outdoor covered dining patio
The remainder of the dining hall design is based on the programmatic needs, however the uniqueness of the construction method allows for an outdoor dining area that is partially covered and enclosed by a skeletal form of the main building construction. Between the buttress walls, the horizontal bamboo reinforcement is left exposed to allow light and air flow into the area, an important concern in the design of all the buildings as it is assumed that there will be no air conditioning. The roof structure is also left exposed and there is no final roofing material placed on top so as to reveal the construction method as an educational example.

Figure 167. Rendered perspective showing the breezeway and patio between the dining hall and kitchen
Figure 168. Transverse Section through Dining Hall

Figure 169. South Elevation of Dinning Hall
Figure 170. Photo of Final Dining Hall Section Model, aerial view showing dining space and entry to patio

Figure 171. Photo of Final Dining Hall Section Model, interior view showing roof structure and seating between buttress walls
Figure 172. Photo of Final Dining Hall Section Model, interior view through dining area and patio with exposed bamboo structure
Figure 173 & 174: Illustration of the construction of the rammed earth framework

Figure 175: Illustration of the ramming of earth into the wooden frames
Figure 176 & 177. Illustration of rammed earth frameworks and the process of moving the framework as the wall is built up

Figure 178. Illustration of ramming the earth around the already placed vertical bamboo reinforcement
Chapter Eleven

Phase III Concrete Reinforced Administration Building

Figure 179. Plan showing location of Phase three administration building within site in pink
The design for the construction of the administration building was mainly influenced by the case studies on improving the durability of earthen construction and the study of reinforced concrete construction as a way to overcome structural issues. The first case study determined that with the addition of as little as 10% concrete to the loam mixture used in both adobe block and rammed earth construction, the durability of the building is greatly improved. With this in mind, the design of this building assumes an addition of 20% concrete to the earth mixture to be used. Along with this addition, the form of the building follows the framework established second case study discussing how certain formal moves can greatly improve the stability of a building.

As with all the other buildings on this campus, the most crucial design move is to assure that the form of the building is a simple shape both in plan and section (figures 19 & 22). By keeping this in mind, the administration building is able to support a second story conference area, a rooftop terrace, and open breezeways between offices on the first floor. (again this building is not designed for air conditioning). As can be seen in figure xx, the structure of this building is based on a system of buttresses that brace the walls to each other as well as create the internal divisions between office spaces. The walls shown in red are the main concrete reinforced load bearing structure for the second story rooms, while the walls represented in white carry the secondary (live) load of the rooftop terrace, but not any additional built structure (dead load). The remaining walls can be though of essentially as break away walls. The design proposed here is built with rammed earth that has no added concrete, however, since these walls are only meant to create enclosure, they could be modified in the construction process to some other technique (the panelized cane mat system for example).
Figure 180. Rendering of the Structural load distribution in the Administration Building
As was mentioned before, the first floor of the administration building is designed with oversized breezeways, possible due to the fact that the interior partitions continue outward to become part of the external buttressing system. By creating this open-air environment, the Administration Building not only serves its functional needs, but also acts as a social area of refuge in the shade of its somewhat monolithic form.

Figure 181. Plan of the first floor of the Administration Building
The second floor of the Administration building houses two conference rooms and an open rooftop terrace. These spaces are designed with the intention for them to supplement the display of innovations taking place in the Gallery/Library building. While the majority of the everyday educational activity will take place in the classrooms and construction yards, the second floor of the administration can serve as a supplementary area that can support symposiums or visiting architects and engineers’ lectures. The rooftop terrace can be used as an extension of this space as it has a direct view down to the activities taking place in the construction yard. It can also be used for more formal events to promote the achievements and growth of the Earth Construction Education Facility.
Figure 183. Transverse section A through the Administration Building

Figure 184. Perspective of the walkway between the Administration Building and the Dining Hall
Figure 185. Longitudinal section B through Administration Building

Figure 186. South Elevation of the Administration Building
Figure 187. Photo of Final Administration Building Section Model, view from street

Figure 188. Photo of Final Administration Building Section Model, areal view from west of roof top terrace
Figure 189. Photo of Final Administration Building Section Model, areal view
Figure 190 & 191. Illustration of floor compositions, section through to the foundation (left) and the finishing of an earth floor (right)

Figure 192 & 193. Illustration of the construction of a second story floor, covering the plywood layer with earth (left) and a section showing the elements of a wood floor system (right)
Figure 194. Illustration of the process of tamping the earth into the wood divisions for the control joints

Figure 195. Illustration of how to properly smooth the top finish coat of an earth floor
Chapter Twelve

Phase IV Gallery Building Construction

Figure 196. Plan showing location of Phase four Gallery and Library building within site in pink
Phase IV Gallery and Library Construction

Given the intent of the Gallery to be a forum for the display of work and innovations being discovered within the Earth Construction School, and the Library’s function as a resource for students, it is only logical for the building itself to display all of the features of the other five buildings. For the Design of this phase, the more rudimentary methods of traditional adobe block construction is used in the basic massing of the building footprint. As the entry is created, the more advanced techniques of the adobe textile blocks (explained in Phase V) is used for the entry wall, and the garden enclosure is created with a spiraling rammed earth element. Each of these parts are intended to show off the varying possibilities within the realm of Earthen construction and showcase the innovations possible without the necessity for an excessive budget.

Figure 197. Perspective of the main site entry plaza looking towards the Gallery on the right
Figure 198. Floor Plan of Gallery and Library Building and garden
Figure 199. Rendering of the corner showing the intersection of the rammed earth garden wall and the diagonal adobe textile wall.
Figure 1200. Section A through Gallery building showing the garden enclosure, reception area, library stacks, and main entrance (left to right).

Figure 201. Section B through Gallery building showing the library stacks, Gallery display area, and garden enclosure (left to right).
Figure 202. North Elevation of Gallery and Library Building
Figure 203. Perspective of Gallery garden area enclosed by the rammed earth wall

Figure 204. Photo of Final Gallery Section Model, view from walkway by the church showing entry from gallery to garden
Figure 205. Photo of Final Gallery Section Model, view from inside looking out to garden

Figure 206. Photo of Final Gallery Section Model, view from plaza looking at rammed earth garden wall and diagonal adobe textile wall
Various building elements in Earthen construction Pamphlet

Figure 207 & 208. Illustrations of wall joint conditions (left) and window attachment conditions (right)

Figure 209 & 210: Illustrations of roof construction; setting the bamboo in place on the roof joists (left), fastening the bamboo to the joists with wood strips (right)

Figure 211 & 212: Illustrations of roof construction; laying cane mat on top of bamboo (left), sealing the roof with adobe plaster (right)
Chapter Thirteen

Phase V “Adobe Textile Block” Church Reconstruction

Figure 213. Plan showing location of Phase five Church Reconstruction within site in pink
Phase V Adobe Textile Block Church Reconstruction

Given the exemplary importance of this building to not only the Earth Construction Education Facility, but to the City of Pisco as well, the design for the church reconstruction is meant to showcase the impressive possibilities of earth construction. The design of this building began with two precedent studies, one of Frank Lloyd Wright’s Textile block houses, and another of works done by office DA, particularly the Toledo house, in Bilbao, Spain. The initial structure comes from Wright’s work, where some of the more formal qualities emerged after seeing the Office Da project.

The textile block system is a unique structural system created by Frank Lloyd Wright in the early 1920’s. The first four houses, all located in California, are the Freeman House, Millard Residence, the Storer House, and the Ennis-
Brown Houses. In these houses Frank Lloyd Wright set about developing a way of concrete blox construction in which the blocks are stacked on top of each other and attached using “a network of inter-block joints, filled with grout and steel reinforced rods, similar to adobe construction in strength and resistance.” The original design of these houses was based on a 16” x 16” concrete block “tile”, with a 1 ½” diameter semicircular channel running along each of the four sides. With this system, when the two blocks are joined side-by-side, a circular channel is created in which a steel bar is placed and then filled with mortar.

This Construction methodology was analyzed for its seismic stability and it was determined that this method of could be improved if the blocks were laid diagonally (creating a diamond pattern) as opposed to stacking them horizontally. By doing this the lateral loads that occur in an earthquake do not have a continuous grout line as there would be in traditional block construction. The loss of these grout lines decreases the areas that the walls can potentially fail, in theory greatly reducing the buildings’ vulnerability to seismic activity.

Figure 218 & 219. Conceptual Renderings of the textile block system established by Wright (left) and the proposed adobe adaptation (right)
The second (formal) portion of this buildings design was based upon the functions needed in a traditional Catholic Church, and the possibilities afforded by this construction method. Looking at the Toledo House By Office Da, a scaffold-like approach is proposed for the construction of this building. By Supporting the structure during the construction, more fluid forms can be achieved producing the folding of the structure over the side chapels of the church. Once the construction has been completed, the internal reinforcing of the textile block construction system ties the entire building’s structure together and the scaffolding can be removed as at this point the building will be able to support itself. In the case of the adaptation from concrete and steel construction system, for the construction of the church, blocks with similar channels are produced in the schools construction yard, and bamboo replaces the steel cross members that fit into these channels. More detailed illustrations of this method can be seen in the end of the chapter in the construction pamphlet.

2 A.P. Vargas, 3
3 A.P. Vargas, 2
4 A.P. Vargas, 3
Figure 222: Plan of the Reconstruction of the Church (phase V)
Figure 223 Section A through church illustrating the framework for the roof spanning the nave

Figure 224. Transverse section B through the nave of the church
Figure 225. Photo of Final Church Section Model, view through the side aisle towards the transept
Figure 226. Photo of Final Church Section Model, view of the diagonal block construction in the transept

Figure 227. Photo of Final Church Section Model, view of the roof assembly
Figure 228. Illustration of the formwork for the plinth of the adobe textile block walls

Figure 229. Illustration showing the placement of the adobe blocks into the bamboo skeleton
Figure 230 & 231. Illustrations showing the application of the first and second mud scratch coats to the exterior of the completed walls

Figure 232. Illustration showing application of the mud-lime finish coat to the church exterior
Chapter Fourteen

Conclusion and Final Campus Plan

Figure 233. Diagram showing the daily activity usage of pisco
Conclusion

The final Design of the Campus for the Pisco Earth Construction Education Facility is based on the final schematic design proposed in chapter Seven- Initial Schematic Design, with minor adjustments made according to the daily use of the site and surrounding areas within the city. The buildings within the site maintained the initial programmatic requirements, while adapting to the construction methods applied to them. The Resulting Facility is intended to demonstrate that no matter the technical skill or economic resources one has, there is always a feasible method of earth construction that can be applied to the construction of a building. As one’s resources increase more options become available, all of which are clearly capable of overcoming the traditionally negative stereotypes surrounding Earth Construction. The durability of a structure can be greatly improved with the addition of readily available materials, and with appropriate design considerations, there is no reason that an Earthen building can be any less structurally stable than comparable contemporary methods of construction.

*Figure 234. Matrix showing the comparisons of proposed construction methods by cost and technical skill*
Figure 235. Final Campus Site plan of the Pisco Earth Construction Education Facility
Figure 236. North Elevation of final camps design

Figure 237. South Elevation of final camps design

Figure 238. East Elevation of final camps design

Figure 233: West Elevation of final camps design
Figure 239. Transverse campus section

Figure 240. Longitudinal campus section
Figure 241. Photo of Final Campus Site Model, view from residential corner

Figure 242. Photo of Final Campus Site Model, view from church plaza
Figure 243. Photo of Final Campus Site Model, view from above
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