TRADITIONAL MATERIALS OPTIMIZED FOR THE TWENTY-FIRST CENTURY

ELIZABETH GOLDEN
University of Washington

INTRODUCTION

The rapid pace of development and economic forces have contributed to the ever increasing complexity of construction, with most building components being manufactured from materials and minerals extracted from locations thousands of miles from the sites where they are installed. In their article, *Global in a Not-so-Global World*, Mark Jarzombek and Alfred Hwangbo observe that "Buildings of even humble proportions are today a composite of materials from probably a dozen or more different countries. In that sense, buildings are far more foundational as a map of global realities...than even a shoe."[1] The current state of architectural affairs is that buildings are less an expression of place, and more an assembled product, created by supply chain logistics and industrial manufacturing processes. Materials are selected from catalogs, with the process of specification most often informed by economic constraints. This discrepancy does not produce unsatisfactory results per se, but benefits can arise when architects and engineers decide to sidestep conventional production scenarios, and choose instead to explore methods of local production and techniques that capitalize on materials with a closer proximity to the building site. This relationship between building, material source and production methods, resembles past construction approaches, where "traditional" materials, such as stone, straw, bamboo, and wood were selected for their accessibility. Of particular interest here is the evolution of earlier production techniques by contemporary means, what historian Wolfgang Ullrich describes as Archaisms, references "...to what has been forgotten and supposedly out-of-date." He observes that these archaisms are essential to invention and progress, arguing that: "A culture that threatens to lose itself in sophistication sporadically requires calibration and to reestablish the roots of its origins and principles. Archaisms are forward looking, as they can open up new perspectives."[2]

Since the industrial revolution, traditional materials such as bamboo and earth have been routinely overlooked due to their unpredictability as more reliable, industrially produced materials became widely available. Today, traditional materials are often associated with poverty in the developing world, and set apart as "alternative" in the developed world. In the US and Europe, industrially manufactured materials such as steel and concrete are represented by trade organizations and manufactures that support testing and promote the use of their materials. With the exception of the wood industry, there have been few organizations and manufacturers willing to invest in the testing and promotion of traditional materials. Consequently, their predictability hardly improved before the 1990s, and traditional construction methods remained relatively unaffected by technological advances in the construction industry. In the mid-1990s, however, many traditional materials saw a strong revival in several countries due to growing concerns about climate change, higher demands for healthier, nontoxic building materials and a newfound desire to reconnect with local culture through indigenous materials. Currently, a small but growing number of architects and engineers around the world are critically reexamining traditional building materials and finding fertile ground for innovation. Material research and testing, in addition to collaborative onsite training, are providing architects with a greater understanding of materials that were previously so unpredictable. The benefits of working closely with the materials are manifold: the reestablishment of cultural connections to local materials, collaboration and knowledge transfer, the advancement of construction methods, and even new building products have been realized by stimulating the evolution of traditional materials and methods. These positive developments can have wide-reaching effects, from challenging public perception of the materials, to promoting larger scale production and use. The following case studies highlight how the recent return to working with traditional materials has advanced their technical evolution, thereby changing their definition from old and outdated, to current and progressive.

FROM BESPOKE TO STANDARDIZED: CONTEMPORARY EARTHEN CONSTRUCTION IN GERMANY

Earth has been used as a building material for thousands of years, and examples of earthen construction can be found on every continent, with some of the oldest existing structures dating back to 351 BCE. In Germany alone, there are more than two million documented buildings constructed out of earthen materials, with remains of the Roman colony Ulpia Traiana being the oldest known examples. As in many other countries, the use of earth in construction fell in and out of favor, based on the scarcity of other materials. *Stampflehm*, or rammed earth, was historically one of the most prevalent types of earthen construction in Germany. Due to a shortage of wood in Europe, a wave of rammed earth construction spread from France to Germany in the 1800s, producing many surviving examples. These include Germany's tallest rammed earth building located in Weilberg an der Lahn, built in 1830. After both of the World Wars, there was a resurgence of rammed earth construction due to the limited availability of other construction materials. In 1947, the Soviet Military Administration in the former German Democratic Republic ordered 37,000 new houses to be built from so called "decent" building materials. It is estimated that around 18,000 rammed earth buildings were built in the GDR between 1947 and 1959. Likewise, West Germany's response to the shortage of materials after the war was to establish temporary building regulations for building with earth, and in 1951, the German Institute for Standardization (DIN) incorporated these codes into the national standards. These standards were revoked in 1971, as the economy boomed and industrially produced building materials became cheap and readily available.[3]

With the demand for more sustainable, natural materials on the rise in Germany, earthen construction again experienced a revival in the 1980s. In 1998, as a result of increasing demand and interest in the material, the *Lehmbau Regeln*, the German earthen building regulations were adopted by eleven of the sixteen German federal states, serving as the first technical norms for building with clay and earth in the European Union. Earthen construction is now a widely accepted practice in Germany due to progressive efforts to promote high-quality training, and to a consistent development of building codes and product standards.[4] In addition to training and standardization, some key projects, such as the Chapel of Reconciliation in Berlin, have helped to change the public perception of earth as a building material.[5] The project's strength lies in its connection to place through its main material, rammed earth. The act of construction was also a vehicle for training, testing and research, adding to the accumulated knowledge about the material and its construction processes. [Figure 1]

The chapel now stands at Bernauer Strasse, one of the most infamous places along the Berlin Wall's former path. For older Germans, hearing the name of the street evokes memories of people jumping from windows to escape from apartment buildings, suddenly captured in the dividing line between East and West Berlin. The wall's construction caused many community buildings and public spaces to be destroyed or cut off from the residents who used them. The Church of Reconciliation was left standing in the no man's land between the border fortifications, separated from its entire congregation living on either side of the wall. The church was destroyed in 1985, just four years before the wall fell, supposedly to keep the sight line open along the border zone. After the fall of the Berlin Wall in 1989, a competition was held for a new building on the site, called the Chapel of Reconciliation.[6] The winning entry was designed by the Berlin architects Reitermann Sassenroth, whose proposal called for an oval shaped sanctuary to be built on the old church foundation. The original design called for the building's core to be constructed out of concrete and the exterior out of glass, which caused much protest from the congregation. Many were uncomfortable with materials considered to represent Berlin's new corporate architecture, and the permanence of reinforced concrete also evoked memories of the Berlin Wall.[7]

Figure 1. The Chapel of Reconciliation, Reitermann Sassenroth Architekten. Photo credit: Ralf Kent

Responding to these concerns, rammed earth was then suggested for the building's core. This material was selected to provide a sense of permanence, while being the only building material that could be returned to its original state with very little effort. Martin Rauch, the rammed earth consultant for this project, calls attention to earth's transitory qualities: "This historic site, where profound tragedy, but also perseverance and survival are manifest, was not to be sealed either in the design or in material. Instead, the goal was to employ minimal gestures and ephemeral materials to inspire remembrance and contemplation."[8] The church's pastor, Manfred Fischer, also appreciated the significance of using earth for the core of the project–recognizing it as a way to restore the no man's land–by referring to it as *Heilerde*, or healing earth, referencing the ancient practice of using earth for medicinal purposes.[9] Along with its inherent metaphorical significance, pragmatic motives also informed the selection: earth's thermal capacity and insulative properties were considered ideal for regulating temperatures in the unconditioned sanctuary.[10]

The construction process became a unique opportunity to study the behavior of rammed earth construction in a larger structure. Because this was the first major contemporary building to be constructed from rammed earth within the Berlin city limits, a special approval process was required. Berlin city authorities imposed structural safety standards seven times higher than for a conventional structure, making material testing and technical expertise essential to the project.[11] Earth from just outside Berlin was selected, and fragments from the destroyed church were incorporated into the mix for the walls of the new chapel, along with linseed fiber for reinforcement.[12] To meet the stringent structural requirements, structural engineers from the Technical University Berlin tested various soil mixes to insure the correct compressive strength of the material used for the project.[13] Additional strength tests utilizing several types of reinforcement were also done on the remaining soil not used in construction.[14] Another exceptional aspect of the project was the wider dissemination of knowledge about rammed earth construction through onsite training. Working closely with the architects and engineers, the earth construction consultant headed the team of mostly volunteer construction laborers. Many on the team were contractors and preservationists traveling from around Germany and Europe for a firsthand experience of working with rammed earth.[15]

Modified concrete formwork was used to construct the sixty-centimeter thick earthen walls, which reach a height of over seven meters. Rather than relying on the addition of cement to strengthen the rammed earth, natural stabilization occurs through colloidal cementation, a process that releases colloids, a natural binder found in clay. The core's thickness and the insertion of concrete at the points of structural transition significantly improve the rammed earth's load bearing capacity. The building's concrete foundation was designed with the center left as a void, permitting a rammed earth floor in the sanctuary. Except for the foundation, the use of concrete was limited to a ring beam embedded in the top of the rammed earth wall. The beam connects the wooden roof to the core, while accepting a majority of the loads.[16] Continuing the use of ephemeral materials within the building, natural finishes are found in several areas. The entry is covered with a dark earthen plaster mixed with coal dust and polished with a wax emulsion. The apse walls are constructed from earth plaster boards finished with an earth and casein plaster, and the floor is rammed earth protected with wax.[17] [Figure 2]

The cumulative effect of the materials is the creation of a building with qualities that have either been forgotten or never before experienced. The rammed earth walls have a texture that concrete could never achieve, and the chapel's surfaces have the imperfections and marks of their making, adding a haptic quality missing from most buildings today. The material's physical properties are surpassed by its potential to link the building to its context. The rammed earth, speckled with fragments of the destroyed church, connects the chapel to the local landscape and to the history of the site.[18]

The chapel has attracted over one million visitors in the last decade, and stands as a testament to the wide appeal of contemporary earthen construction, while also meeting current German building regulations. The construction of the Chapel of Reconciliation marked the beginning of a series of studies carried out by a team of engineers including Christof Ziegert, one of the researchers from the TU Berlin involved in the soil testing for the project. These tests, funded by the German Federal Institute for Materials Research and Testing, have been used to create guidelines for the standardization of several earthen building products such as earthen masonry. These standards have increased the material's reliability to the point that many earthen products are equal to conventional ones currently on the market.[19]

Testing and standardization mark a new era for earthen construction, with a possible shift away from local production to mass production and distribution. Over fifty firms in Germany now offer products from earthen drywall to clay plaster.[20] Earthen building products are in even higher demand now due to the increase in super-insulated buildings over the past ten years. Concerns about indoor air quality

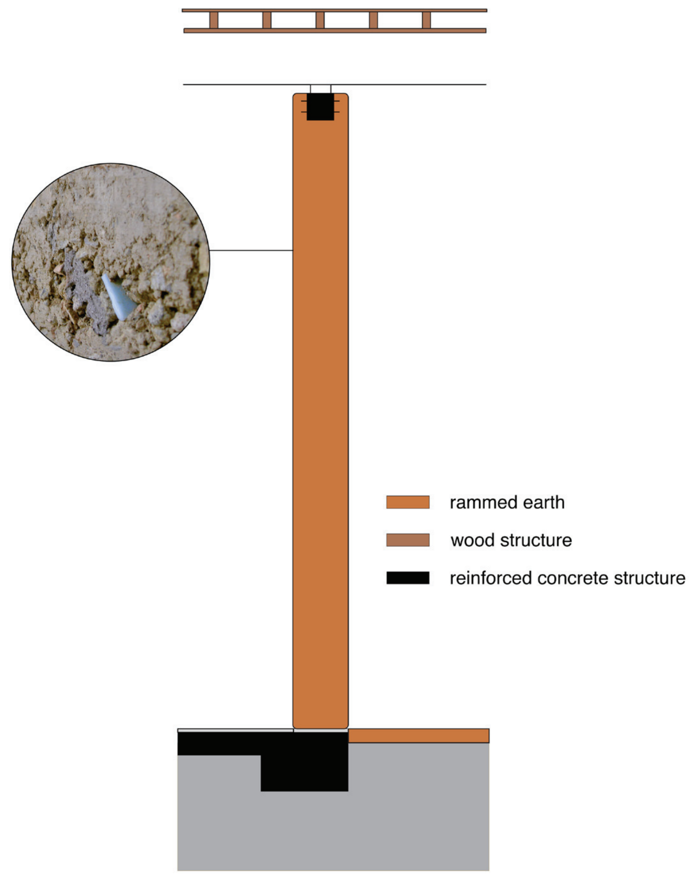

Figure 2. Section through the rammed earth core.

in these airtight buildings have led many to select earthen finishes for their building interiors.[21] It remains to be seen if the process of "industrialization" will completely transform earth's identity from a handcrafted material to a conventional building product. Earthen construction in Germany has undergone a higher level of development in the past two decades than over the past thousand years as its value has shifted from a substitute in times of scarcity, to a viable alternative with positive benefits.

Technology Integration: Traditional Materials in Contemporary Chinese Construction

Growth in many developing countries threatens to erase rich traditions of building with local materials. Traditional methods of construction have been gradually replaced by practices that are cheaper and faster, while the benefits of building with native, natural materials are being overlooked or forgotten. China's transformation over the past thirty years, from a planned to a market economy, illustrates this shift very distinctly. Immense population growth caused housing shortages in the 1980s, and led to a steady move from traditional materials, such as wood and earth, to prefabricated concrete systems. [22] The result of this shift from traditional methods to industrial ones is clearly visible throughout China today, as historian Ronald Knapp observes,

"...the acceptance of new designs and materials has ruptured links with local styles and building conventions, bringing about a striking homogenization of housing in a country once known for a diversity of local traditions."[23]

The pressure of development has also initiated the widespread demolition of village dwellings, destroying many culturally significant examples of traditional Chinese architecture. The Chinese State Administration of Cultural Heritage estimates that China has lost over 30,000 historic sites since 1982.[24] The issue of demolition brings with it a wide range of public opinion, with some regarding it as an inevitable step toward improving living standards, while forced evictions have caused widespread unrest in many parts of the country.[25] The circumstances for traditional architecture remain difficult at best, while attempts to preserve historical buildings in parks, or rebuilding perfect replicas highlight the predicament of conserving structures that can no longer meet the scale of China's demands for growth. The materials common to traditional construction have many deficiencies and are consequently not considered as viable or even desirable for use in new construction. Clearly, there is a strong need for Chinese traditional building culture to respond and adapt before it becomes completely obsolete.

Since its inception in 1997, Amateur Architecture Studio has been exploring the gap between traditional building methods and contemporary construction practices, often experimenting with traditional, local, and found materials in new and innovative ways. Much of the work by the Hangzhou-based studio is shaped by their close relationship to the materials they select for their projects, and the craftsmen working on site. Wang Shu, the founder of the studio recognizes the importance of reconnecting to local culture through indigenous materials, asserting that traditional methods must evolve in order for this to occur: "China can civilize modernity by its culture. The architect must solve the problem of how to make traditional materials...compatible with modern architectural technology."[26] The name "amateur" reveals the studio's working methodology as an informal, experimental process, associated more closely with artisans than with professional architects.[27] The Ningbo Museum is one of Amateur Architecture Studio's most prominent works combining traditional materials with contemporary methods. The building caused much controversy during its construction because portions of the facade were fabricated out of reused masonry from demolished buildings. Government officials questioned whether old materials were the right choice for the project, as Wang recollects, "During the design and construction process, I was accused of creating something that reflects the most outdated appearance of Ningbo in the most modernized district of the city."[28]

The Ningbo Museum of History occupies what was once farmland, located at the edge between the city and countryside. As one of China's oldest cities, Ningbo has a rich history, though some historic areas have been destroyed in recent years to make way for new development. The museum is located in Yinzhou, a new district of Ningbo that was created by razing dozens of old villages. Faced with building in a "no memory zone" devoid of context, Amateur Architecture Studio resolved to create an artificial landscape reminiscent of the mountains surrounding the site. The architects employed the language of valleys, caves, and streams to shape the mass of the building, while the natural colors of the masonry facades further enhance the museum's connections to its surroundings.[29] [Figure 3]

Figure 3. The Ningbo Museum of History, Amateur Architecture Studio.
Photo credit: Thomas Stellmach

The material for the facade was saved from the local village demolition sites and assembled using a masonry technique common to the area, called *wapan*. This traditional construction method was developed as a response to frequent typhoons, allowing people to rebuild quickly with fragments of building debris–terra cotta tile, stone, and brick–remaining after the storms. Wang had been studying and working with the technique for several years before the museum's construction, and had originally been attracted to reusing old tiles and bricks because of their quality and low price.[30] Wang also understood the significance of repurposing demolition material in new structures, and had first used the technique for the Chinese Pavilion at the Venice Biennale in 2006, to make a clear statement about village demolition. The revival of *wapan* construction by Amateur Architecture Studio could also have been a response to a ban on the production of solid clay brick and tile by the government in 2000, which was enacted in order to preserve land and reduce the country's CO_2 emissions.[31] The ban highlights the unsuitability of traditional masonry for large-scale use, but it also marked the end of a building practice dating back to the Han Dynasty in the third century BCE.[32]

The museum is the studio's largest structure to employ the use of wapan, and many studies were conducted to develop a suitable technique for such a large scale project. Typically, traditional wapan walls can achieve a height of three meters, and the walls at Ningbo required a surface up to twenty-four meters high.[33] Initially, the challenge was to find craftsmen who could recall how to execute wapan construction. Wang used photos from his earlier research to help the craftsmen remember the technique.[34] Under close consultation with the architect, over twenty different test walls were constructed on site, with the final prototypes creating a

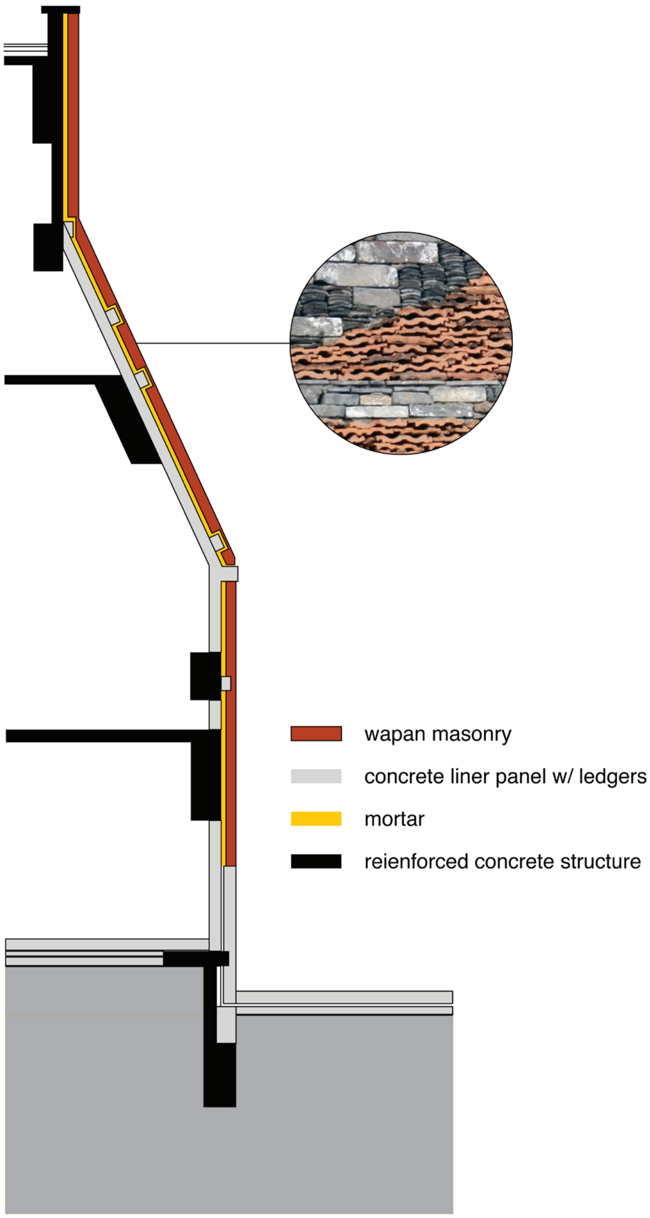

Figure 4. Section through the *wapan* masonry facade.

facade system from the wapan masonry and mortar, combined with a concrete liner panel. The compressive strength of the masonry was low, and required the periodic support of invisible concrete ledgers integrated horizontally into the panel every three meters. The entire facade system is tied back to the main concrete structure and acts as the weather barrier for the building. [Figure 4]

Because *wapan* had never been used in a contemporary structure, existing masonry codes formed the basis for regulating the construction, and the *wapan* prototypes served as an important tool for convincing local officials of the structure's viability.[35] The trial and error method of working also informed the facade's appearance. Although the architects had prepared CAD drawings for every face of the building, the handmade nature of the construction did not allow for exact execution of the architect's design. Wang recalls that "...the design be[came] a collective work of the craftsmen, exceeding personal creation, and out of the engineer's control."[36] The craftsmen's newfound skills also continued to be of benefit even after the museum's completion, with many finding work as *wapan* masons on subsequent projects. [37] [Figure 5]

Figure 5. The *wapan* facade: "a collective work of the craftsmen." Photo credit: Marco Capitanio

The museum facades transform a waste material into an environment permeated with meaning, serving as a reminder of village demolition while simultaneously presenting a contemporary translation of traditional masonry construction. *Wapan*, once considered a lowly material of the poor, is reinforced in a manner that permits it to function on a scale demanded by contemporary Chinese standards. Since opening in 2008, the museum has received much media attention, public acceptance, and admiration.

Amateur Architecture Studio's investigations are not limited to any one material, and the studio continues to experiment with other traditional materials and methods in their more recent work. It will be interesting to observe how the firm influences contemporary Chinese architecture now that Wang Shu has won the Prizker Prize and the studio's work has been internationally recognized. He will likely have further influence on young architects in his role as dean of the School of Architecture at the China Academy of Art in Hangzhou. Traditional construction methods are at the core of his new curriculum for the school, which requires students to study carpentry, bricklaying, and traditional construction techniques. There are currently a handful of architects in China known for working with traditional materials, such as Standard Architecture, Li Xiaodong Atelier, and Edward Ng. Perhaps more will emerge in the coming years. Because large scale industrialization and development in China is a recent phenomenon, ties to traditional culture are still very fresh, making this a crucial moment for the future of Chinese architecture.

CONCLUSION

The reemergence of the traditional methods and materials–earthen construction in Germany and *wapan* construction in China–came at a time when concerns for the environment and apprehensiveness about development were high. Political and economic circumstances created an environment that either provoked or encouraged a return to the use of traditional materials, and their selection for the chapel and museum responded to a recent trend in development in both countries. Earth acted as a foil to the new glass and concrete buildings of Berlin, and *wapan* became a commentary on the Chinese government's erasure of the past in the name of progress.

More importantly, the materials fulfilled pragmatic requirements while also offering possibilities that conventional ones could not. Materials originating in the surrounding landscape connect to local geography and culture, while the inherent weakness and unpredictability of *wapan* and earth provide opportunities for engagement and experimentation. The materials were adapted and enhanced beyond their original capacities, and a physical verification process was used to convince local authorities of the material's structural performance. The strengthening of the materials was achieved through modern methods, by testing and developing hybrid systems utilizing both traditional and conventional materials. The Chapel of Reconciliation and the Ningbo Historic Museum confirm that traditional materials can indeed be viable in the twenty-first century, but their calibration requires a careful balance between technical analysis and cultural expression.

The recent return to traditional materials and methods moves beyond an idealized revival of anachronistic practices, and focuses instead on enhancing material performance by contemporary means. The work of architects such as Võ Trong Nghia in Vietnam, Francis Kéré in Burkina Faso, Lotus Praxis Initiative in India, exemplifies this trend, and explores the boundary between traditional and modern technology in new and innovative ways. Traditions come and go, and construction methods fall in and out of favor, while many non-industrial materials have remained at the fringes of mainstream construction. Issues surrounding development and environmental degradation will continue to motivate architects to explore other methods of construction outside of conventional scenarios, and these seemingly small, local responses could become valuable paradigms for the future.

ENDNOTES

1. M. Jarzombek and A.B. Hwangbo, "Global in a Not-so-Global World," *Journal of Architectural Education* 64, n.2 (2011): 59-65.
2. Wolfgang Ullrich, "Vom Ursprung der Fuelle und Vielfalt," *Werk, Bauen + Wohnen* 3 (2008): 4-7.
3. Klaus Dierks and Christof Ziegert, "Zur Geschichte des Stampflehmbaus" in *Stahlbetonbau Aktuell 2002*, ed. R. Avak and A. Goris (Berlin: Bauwerk Verlag, 2001), 21-29.
4. Ulrich Röhlen and Christof Ziegert, *Lehmbau-Praxis Planung und Ausführung* (Berlin: Bauwerk, 2010), 3. Röhlen and Ziegert recognize the German Association for Building with Earth as the primary organization behind establishing building codes and product standards for earthen construction in Germany. The organization also offers vocational training recognized by the German Chamber of Trade and Commerce.
5. Ibid., 6. Röhlen and Ziegert cite the use of rammed earth in the Chapel of Reconciliation and earthen plaster in Peter Zumthor's Kolumba Museum as examples that transform earth's identity from "brown and crumbly" to contemporary and sophisticated.
6. Background behind the construction of the Chapel of Reconciliation from U. Braun and W. Huber, *Versöhnungskirche: Kapelle der Versöhnung in Berlin* (Berlin, Evangelische Versöhnungsgemeinde, 2003).
7. Manfred Fischer, "Zwischen Glas und Stahl - Lehm," *Reformatio* 3 (2002): 190.
8. Otto Kapfinger and Martin Rauch, *Rammed Earth* (Basel: Birkhäuser, 2001), 83.
9 Manfred Fischer, "Zwischen Glas und Stahl - Lehm," *Reformatio* 3 (2002): 190.
10. Ibid.
11. Otto Kapfinger and Martin Rauch, *Rammed Earth* (Basel: Birkhäuser, 2001), 82-90.
12. Thomas Wieckhorst, "Weicher Kern – luftige Hülle," *Bauhandwerk* 11 (2003): 20-29.
13. Dachverband Lehm e.V., "Kapelle der Versöhnung, Berlin," Dachverband Lehm e.V., http://www.dachverband-lehm.de/projekte/DVL_lehmbau-projekte_kapelle_berlin.pdf.
14. Klaus Dierks, Eddy Widjaja, and Christof Ziegert, "Bewehrung im Stampflehmbau," in *Moderner Lehmbau 2003: Nachhaltiger Wohnungsbau - Zukunft Ökologisches Bauen*, ed. Peter Steingass (Stuttgart, Fraunhofer IRB Verlag, 2003), 21-29.
15. Otto Kapfinger and Martin Rauch, *Rammed Earth* (Basel: Birkhäuser, 2001), 90.
16. Thomas Wieckhorst, "Weicher Kern – luftige Hülle," *Bauhandwerk* 11 (2003): 20-29.
17. Otto Kapfinger and Martin Rauch, *Rammed Earth* (Basel: Birkhäuser, 2001), 83.
18. Adam Sharr observes the connections made through the material to the history of the site: "...the rammed earth literally sediments together countless deposits of memory into built form." Adam Sharr, "The sedimentation of memory," *The Journal of Architecture* 15, n.4 (2010): 509-510.
19. Urs Müller, Christof Ziegert, Caroline Kaiser, and Ulrich Röhlen, "Eigenschaften industrieller Lehmbauprodukte für den Mauerwerksbau und Verhalten von Lehmsteinmauerwerk," *Mauerwerk* 16, n.1 (2012): 17-27.
20. Peter Steingass, "New Chances for Modern Earth Building," in *Moderner Lehmbau 2003: Nachhaltiger Wohnungsbau - Zukunft Ökologisches Bauen*, ed. Peter Steingass (Stuttgart, Fraunhofer IRB Verlag, 2003).
21. Jola Horschig, "Reine Formsache" *DB : Deutsche Bauzeitung* 141, n.3 (2007): 65. Research suggests that the high sorption capacity of earth makes it ideal for regulating moisture in spaces with low air exchange rates.
22. Ronald G. Knapp, *China's Old Dwellings* (Honolulu: University of Hawai'i Press, 2000), 326.
23. Ibid.
24. Tania Branigan, "China loses thousands of historic sites," Guardian, December 29, 2009, http://www.guardian.co.uk/world/2009/dec/14/china-historic-sites-survey.
25. Louisa Lim, "China's Demolition Derby Turns History Into Rubble," National Public Radio, February 8, 2012, http://www.npr.org/2012/02/08/146578746/home-of-noted-beijing-architect-reduced-to-rubble.
26. Xu Wenwen, "Honored architect goes his own way," Shanghai Daily, March 9, 2012, http://www.shanghaidaily.com/article/print.asp?id=496163.

27. The Hyatt Foundation Media Information Office, "Wang Shu 2012 Laureate Media Kit," Hyatt Foundation, http://www.pritzkerprize.com/sites/default/files/file_fields/field_files_inline/2012-PritzkerPrize-Media-Kit.pdf.
28. Till Wöhler, "Ningbo Museum" *Architectural Review* 227, n.1357 (2010): 58.
29. Brendan McGetrick, "Ningbo History Museum" *Domus* 922, (2009): 66.
30. Wang Shu, "Architecture with Hands," (lecture, Rice University, Houson,TX, October 12, 2011).
31. Alicia Robbins, Paul Boardman, John Perez-Garcia, Rose Braden, *China Sourcebook: An Introduction to the Chinese Residential Construction and Building Materials Market*, (Seattle: University of Washington, 2004), 6.
33. Ronald G. Knapp, *China's Old Dwellings* (Honolulu: University of Hawai'i Press, 2000), 116.
33. Wang Shu,"Der Berg" *Bauwelt* 100, n.37 (2009): 22-27.
34. Brendan McGetrick, "Ningbo History Museum" *Domus* 922, (2009): 66.
35. Han Yude, Wu Quingbing, and Chen Haiyan, "Construction Technology on Tile Wall in Ningbo Museum" *Journal of Construction Technology* 39, n.7 (2010): 93-95.
36. Wang Shu, "Wang Shu," in *After the Crisis*, ed. Josep Lluís Mateo (Baden, Lars Müller Publishers, 2011): 51.
37. Ibid.,52.

Illustrations are produced by the author.