Natural Building in the City: Salutogenic Construction Materials and Techniques in Urban Environments

JOSEPH F. KENNEDY
NewSchool of Architecture + Design

Recent decades have witnessed a resurgence of vernacular building techniques based on materials such as earth, lime, stone and straw. These methods are commonly known as "natural building." Renewed interest in vernacular and new natural building techniques such as straw-bale construction, compressed earth blocks, hemp-lime, and earthbags, as well as hybrid systems with conventional construction, has been driven by several factors, including: economy, environmental concerns, cultural interests, community building, and aesthetics. But much of the attention to these techniques has stemmed from their salutogenic (health-supporting) qualities, including the absence of artificial chemicals. Indeed, many early natural buildings were built for clients suffering from multiple chemical sensitivities. These clients, as well as their architects and builders, pioneered the adoption of these methods into contemporary building codes. Natural building methods also support human well-being in ways that have been mentioned anecdotally, but are difficult to measure, such as: tactility, light modulation, as well as through their hygroscopic and/or acoustic properties. Most natural building techniques also support planetary health, as they are often local, have low-embodied energy, and/or can sequester carbon.

Parallel to (but largely separate from) the growing interest in natural materials has been the recognition of the importance of creating healthy cities. While most natural building systems have been utilized in rural, village, or suburban conditions, some natural builders have begun to explore natural building in the city. This paper will address the possibilities and constraints of using natural building in urban conditions, including contemporary urban cores as well as rapidly urbanizing informal peripheries of cities in the developing world. It will discuss issues such as codes, structure, material availability, durability, low to mid-rise viability, as well as trends that can either allow or hinder the use of natural building systems in urban environments. Building health metrics such as WELL will be utilized to help understand the health impacts of natural building in contemporary urban development. This study will also include a discussion of extant historic urban environments and buildings, current case studies, and visionary ideas for integrating natural building into cities, including an exploration of hybrid approaches to creating healthy urban environments using natural, conventional and emerging technologies.

INTRODUCTION

In recent decades building with natural materials has been a rural, village or suburban phenomenon. But as we are now an urban species, interest in applying these techniques in the city has grown. But while use of earth, straw, wood and other natural materials has recently surged in developed nations, they are being abandoned in developing nations at an alarming rate (Onyegiri and Diogu 2013). But as designers adopt human wellness as a design imperative, use of natural building materials has risen due to their salutogenic effects (Baker-Laporte and Laporte 2015) (Figure 1). This paper is an initial assessment of the constraints and possibilities regarding natural building methods in cities, so that strategies using these salutogenic techniques can be further developed to improve human, societal and planetary health.

WHAT IS NATURAL BUILDING?

According to Michael Smith, "[n]atural building is any building system that places the highest value on social on social and environmental sustainability" (M. Smith 2015). Natural building comprises methods of construction that are:

- Dependent on minimally processed materials,
- Biophilic: Healthy for workers and inhabitants,
- Low-embodied energy in their material, construction and operation,
- Ecologically sustainable, and even regenerative,
- Locally available and (ideally) affordable,
- Derived from tradition, but applicable to today's needs,
- Recylable and reusable within a cradle-to-cradle approach to design.

While knowledge gap has arisen due to the loss of skilled practitioners of many old techniques, many natural building systems have recently been revived, using extant historic buildings examples as "texts" (Kennedy, Smith and Wanek, The Art of Natural Building 2015). Many builders have found, however, that as many of these methods are unrealizable due to loss of traditional materials (wood, thatch, etc.) due to overharvesting, climate change, etc., they must be adapted to current conditions. In addition there is a general lack of natural building expertise, and many more skilled practitioners (design, construction, and engineering) are needed to meet growing demand (Magwood 2016).

NATURAL BUILDING AND PLANETARY HEALTH

Planetary heath is a precursor to human health. To reduce climate impact, buildings must reduce resources, carbon and energy in their construction, use and maintenance. Sustainable harvest and transport of materials is key to this goal. Carbon sequestration through the use of wood, straw, hemp and other high-carbon building materials in durable buildings could help absorb excess CO_2 from the atmosphere. In addition, sensitive and restorative site planning using local and natural materials can facilitate habitat preservation and improve biodiversity.

URBANISM AND HEALTH

The use of natural building in cities is part of a larger trend called "healthy urbanism," which posits that human and societal health can be improved through active- and biophilic design and planning. Assessment tools such as the Living Building Challenge (International Living Future Institute 2014) and LEED Neighborhood Development are used to measure urban health. The Urban Land Institute's Building Healthy Places initiative sets various criteria and provides a toolkit for urban well-being (Urban Land Institute n.d.). The field of Active Living Design promotes design for physical activity through, for example, making the use of stairs more attractive. Smart Growth and Transit Oriented Development have the goals of reducing pollution, improving social health, and creating more livable cities by increasing density and reducing dependence on the automobile.

NATURAL BUILDING IN HISTORIC CITIES

Natural materials were the rule in urban construction until very recently. Examples of earth, wood, and stone buildings, hundreds (or even thousands) of years old, can still be found in historic urban cores around the world (Figure 2). Other examples have been lost to degradation or conscious destruction (De Felippi

Figure 1: A salutogenic house – timber frame with light-clay insulation, plastered with earth plaster and finished with natural paint. Photo credit: Paula Baker-Laporte.

2006). Some cultures recognize the value of this vernacular built heritage, and protect and promote it as a living tradition. In fact, historic conservation can provide lessons for new construction (Preprints Terra2016 2016). Urban trends indicate the need for innovation in new natural building techniques. These strategies include greaterapplication of building science to vernacular strategies, engineered natural building materials, and hybrid systems with industrial building materials such as steel and concrete (Wanek 2010).

A CRITICAL OVERVIEW OF NATURAL BUILDING SYSTEMS

Earth

Building with earth (adobe, rammed earth, etc.) is still common, with hundreds of millions of people living in earthen houses, but

NATURAL BUILDING AND THE "5 S'S" OF ARCHITECTURE

Architect Robin Brisebois has distilled the essence of building to the "5 S's": Site, Space, Structure, Skin and Systems (Brisebois 2016). Table 1 outlines the practical potential of natural building methods in urban environments utilizing this classification system.

The "5 S's" (per architect Robin Brisebois	**Notes on natural building in urban environments**
Site: size and shape; slope; legal restrictions; orientation; outdoor spaces	• Match site and appropriate techniques per availability, codes and zoning, seismic and other considerations. • Use living materials and natural materials for landscape design. • Create outdoor rooms with buildings using living walls and roofs. • Building as site to create habitat for other species.
Space: program; organizational principles; circulation.	• Use good passive design to maximize effectiveness of materials. • Use natural materials with appropriate programmatic uses.
Structure: material; system; primary and secondary	• Primary structural systems are the most challenging aspect of natural building in multi-story urban contexts. • Need to be especially aware of seismic and extreme weather challenges. • Currently natural building is very possible in low-density areas of cities.
Skin: material; detail; climate	• Most common current use of natural building systems in all cases. • Wall systems: straw, earth, fiber/clay hybrids, fiber/lime hybrids, stone. • Interior finishes currently most common application of new natural building in cities. Exterior finishes possible, but more challenging due to exposure, especially for tall buildings. • It is critical to match material to climate. For example: minimize thermal mass construction in hot humid climates. • Proper detailing is critical for longevity of natural building materials, especially in cold climates. Building science should be rigorously applied. • Industrial and natural material hybrids need to be very carefully detailed to avoid moisture issues, i.e. avoiding cement plaster over earthen walls. • Avoid waterproof coatings and membranes. Use rain screens and air barriers instead.
Systems: mechanical, electrical, plumbing; integration	• Natural building materials work well with passive design strategies. • Certain hygroscopic materials such as clay can buffer humidity levels. • Other materials help to provide thermal mass and/or insulation. • Mechanical and other systems need to be integrated in such a way so not to damage or impact natural building processes.

Table 1: The "5 S's" of architecture and notes on how natural building can be applied in urban construction.

Figure 2: A several-hundred-year-old traditional timber frame house with wattle and daub infill in a northern European city. Photo credit: Catherine Wanek.

the number has decreased dramatically in recent years. Adobe (mud brick) is straw-rich clay mud poured into forms and sun dried and is typically used in non-seismic rural areas in hot arid climates. Adobes can be formed into woodless vaults and domes, but only in the driest climates due to danger from roof collapse when wet. Cob is a monolithic mix of clay, sand and straw, with a similar material makeup as adobe.

Rammed earth is a mix of water, sand and clay that is tamped between forms. Compressed earth blocks (CEBs) use a similar mixture as rammed earth, but are mechanically pressed to create precise blocks, which are placed in a manner similar to adobe. CEBs have also been used in woodless construction. Earthbags are soil-filled sacks or tubes tamped into place to create walls or domes. Earthbags have proven to be excellent for rebuilding in post-disaster scenarios, as they are earthquake resistant and quickly erected. Earthbag construction does rely on polypropylene bags or netting, but modest use of these industrial materials provides capacity to use a wide range of low- or no-embodied local materials. Stabilization with cement negates the environmental value of any earthbuilding system (Preprints Terra2016 2016) and height limits and extensive reinforcement are necessary in earthquake-prone areas.

Strawbale construction

Strawbale construction refers to baled blocks of straw stacked into loadbearing or infill walls (Steen, Steen and Bainbridge 1994). This method has become very popular and has met with wide acceptance since its revival in the early 1990's. Widely built in North America, Europe and Australia, strawbale construction has recently been accepted into the International Residential Code (International Code Council 2015). It has excellent seismic resistance, and works well with earth or lime plasters. One or two story buildings are common, but straw-bale buildings of multiple stories are beginning to be built.

Hybrid natural construction

Many types of earth/fiber hybrids are possible, with a range of mixtures from pure earth to pure straw. Leichtlehm (also known as straw-clay, light straw clay) is a traditional German system of coating straw with clay slip then tamping this mixture between forms. This provides an ideal mix of insulation and thermal mass (Baker-Laporte and Laporte 2015). Other cellulose materials (wood chips, paper, hemp, rice hulls) have also been used in a similar fashion. Lime has also been used as a binder. Hemp and lime mixtures are colloquially called "hempcrete". These fiber/binder mixtures have also been

Figure 3: Applying earthen plaster to a strawbale winery in Healdsburg, California. This winery keeps wine and people naturally cool. Photo credit: Joseph F. Kennedy.

used to create lightweight blocks. Wattle and daub is a weaving of flexible wooden or bamboo sticks or staves as infill between a structural frame, which is then coated with a lime or earthen plaster.

Natural paints, plasters, renders and floors

Earth and lime plastering is common on strawbale, cob, adobe and leichtlehm and can be used for both interior and exterior finishes (Figure 3). Alis is a paint made of clay, casein and fine sand, which can be applied to a range of surfaces (Crews 2015). Clay, lime, and casein-based interior natural paints and plasters are the most common natural building intercession in existing urban buildings, as they can be applied over conventional materials (Crimmel 2016). Tamped or poured earth floors are usually sealed with a drying oil and wax. Earth floors can be placed on top of existing floors of sufficient stiffness.

Wood

Traditional timber framing was common in traditional cities, but is now limited due to deforestation concerns. Round pole timber uses small diameter trees, but is not practical in cities unless for non-structural uses. But wood has a very promising urban future, as wood composites are easy to construct at multiple stories and can sequester high levels of carbon.

Stone

Stone buildings are the oldest extant buildings on earth. Local stone has a place in urban buildings, especially in non-seismic areas, and for decorative purposes. Due to its weight, however, the transport of stone far from its source negates its environmental value.

Bamboo

Responsibly farmed and harvested bamboo can provide a renewable building material in tropical areas of the world. In these climates it can grow to timber size in a fraction of the time as wood. Innovative treatment (against insects and rot) and joinery (with metal and concrete) of bamboo can extend its life beyond the limited lifespan of traditional bamboo structures. Extensive bamboo scaffolding structures in Asia show its possibility in urban environments.

Building with recycled materials.

The most common “natural” materials in urban environments derive from the waste stream. Careful deconstruction of existing buildings and infrastructure (sidewalks, etc.) can provide materials for new buildings. Other creative uses of recycled materials include building with tires, which are commonly used in peri-urban cities. Tires and other recycled materials such as glass, paper, and plastics can be utilized as feedstock in the creation of composite materials.

HUMANS, BUILDINGS AND HEALTH

The WELL Building Standard (International WELL Building Institute n.d.) is used to measure a building's impact on human health, and has been chosen to survey (as shown in Table 2) how natural building materials can contribute to human wellbeing.

CONSTRAINTS OF USING NATURAL MATERIALS IN URBAN ENVIRONMENTS

While natural materials can contribute to planetary, social and physical well-being, numerous constraints exist. Physical constraints include seismic concerns, hurricanes, tornados, etc. The thickness of some natural wall systems (i.e rammed earth or strawbale) may not be viable for tight lots or high per-square-foot value land. Weather and climate concerns preclude the use of specific materials in certain climates. The most challenging areas are cold climates, but recent advances in building science have led to more robust natural building details in these regions (Racusin and McArleton 2012).

Few natural materials can be sourced in cities, and access to such materials is a big concern due to the high environmental cost of transport. It is also difficult to stage many natural building systems in cities due to lack of space (Welch 2016). Some natural builders have addressed this through pre-manufacturing systems off-site. Rammed earth, straw panels and wood composites are examples of this approach. Existing building stock can be utilized creatively, with a "deconstructionist" approach to disused buildings. Indeed, most non-toxic or natural materials available in cities are in old building stock. Use of local resources can help cities regain regional character.

Negative attitudes against adoption of natural materials in urban environments are the most challenging constraints to address. Natural building is often seen as outdated or associated with poverty (Kennedy and Perry 2014). Other concerns include durability and maintenance, design and engineering limitations, as well as stylistic and material constraints in historic districts. There is also the subtle problem of "patinaphobia" (Kapfinger 2015), where the natural aging of materials is not accepted. Because of these powerful disincentives, natural building techniques must be improve, rebranded and promoted for acceptance.

POSSIBILITIES OF NATURAL BUILDING IN CITIES

New natural buildings in cities are few but growing in number. This increase is due to climate laws and environmental and health concerns, as well as aesthetic interest. This resurgence is largely centered in Europe, where codes and zoning regulations are more accepting of these techniques (Preprints Terra2016 2016). Germany is a leader in many natural building systems, due to fortuitous planning decisions for rebuilding the country after World War 2. Recent breakthroughs have led to code acceptance of some natural building systems in the US (International Code Council 2015). However, ASTM standards are necessary for other natural building systems to gain widespread acceptance in the US. Public investment into research and development is needed as there are few industry associations to cover costs.

As many natural building materials (such as unreinforced earth) have weak structural properties, height limits are necessary, especially in seismic, hurricane, and other high risk areas. This is a problem when increased density is desired. But hybrid innovations could address these issues, through combining compressive strength materials such as earth with high tensile strength systems such as wood, bamboo or steel (Wanek 2010). Often the most ecological urban design in cities is sensitive reuse of existing buildings. Some natural builders are improving the comfort, aesthetics and energy performance of existing buildings through the use of natural materials. An example is wrapping an underinsulated concrete block home in Tucson, Arizona with strawbales and natural plasters and paints (Kennedy and Bjornson 2015).

EXAMPLES OF NATURAL BUILDING IN URBAN ENVIRONMENTS

There is a great need to survey the current state of natural building in urban environments, a task beyond the scope of this paper. While vernacular natural buildings still exist worldwide in many historic urban cores, new natural building construction is most advanced in Europe (Figure 4). There are some examples in North America, but mostly at the residential scale. The situation is Asia is understudied and needs further research. Latin America has many existing vernacular examples, but needs further research to discover new examples. The author has not come across any examples of new urban natural construction in sub-Saharan Africa, where traditional techniques are currently most under attack, though the pioneering work of architect Diébédo Francis Kéré points to a potential direction for new natural construction in urban Africa. A few new natural buildings have been built in North Africa and the Middle East, but many more historic examples have been abandoned or destroyed (Fisk 2012).

Urban strawbale and earth building in Europe

The recent European Straw Bale Gathering describes a range of multi-story strawbale buildings built since 2001 in Europe (Urban Straw Bale Solutions in Europe 2015). Many of these have been built in urban areas. There are many examples of historic multi-story buildings built of earth (pise) in the Lyon region of France. New pise projects have been built in recent years, especially in France, Germany, Austria and Australia (Preprints Terra2016 2016). The following examples only scratch the surface of what is likely built or planned, and point to the need for a systematic census of natural buildings in cities around the world.

Bamboo in Colombia

Timber-scale bamboo construction has been pioneered by architects Oscar Hidalgo and Simón Vélez, who have demonstrated how bamboo can replace timber for large span structures (DeBoer 2015). Innovative bolted metal/concrete connections help to solve some of the structural weakness of bamboo in bending. While their buildings

WELL Category	***Subcategory*** – ways in which natural building materials can help comply.
Air	***VOC reduction*** – they do not contain VOCs (volatile organic carbons). Some drying oils must be utilized carefully.
	Air filtration – lack of a moisture barrier allows air to transpire through materials.
	Construction pollution management – as they are compostable or mineral that can be responsibly returned to the earth.
	Fundamental material safety – they are inherently nontoxic.
	Humidity control – clay and lime are hygroscopic, allowing for natural humidity modulation.
	Toxic material reduction – they are inherently nontoxic.
Water	***Inorganic contaminants*** – they do not contain artificial chemicals so will not contaminate water sources.
	Organic contaminants – organic natural materials will decompose in the presence of water. If improperly built, mold can be a problem with some natural building systems.
Nourishment	***Fruits and vegetables*** – many natural buildings feature living systems. These can be food producing.
	Food production – vertical walls, balconies, and rooftop gardens can be integrated into natural buildings.
Light	***Solar glare control*** – clay and lime based plasters and paints are naturally matte and can be utilized to control glare with proper fenestration design.
	Color quality – clay and lime based paints can have inherently pleasing colors derived from natural and earth-based pigments. Subtle variations engage biophilia (the positive impacts of nature).
	Surface design – subtly variable surface treatments are similar to surfaces found in nature.
Fitness	***N/A.*** Dependent on design – though many methods are labor intensive, can engage a range of people, and allow for community building processes.
Comfort	***Exterior noise intrusion*** – clay and/or fiber-based systems (strawbale, straw-clay, earth, hempcrete, etc.) are sound absorbing or mitigating.
	Internally generated noise – variable surfaces and sound dampening materials help to dissipate internal sounds.
	Thermal comfort – clay or lime/fiber mixtures are ideal for passive design, as they combine insulation and thermal mass.
	Olfactory comfort – absence of volatile organic compounds contributes to a comfortable olfactory environment. Care must be taken with drying oils.
	Reverberation time/sound reducing surfaces – many systems have naturally sound absorbing/dissipating qualities
	Radiant thermal comfort – materials such as earth, stone and lime are ideal thermal mass when used with radiant heating and cooling strategies.
Mind	***Integrative design*** - natural building systems, because of their multiple benefits, are a natural fit for integrative well-building strategies
	Beauty and design – materials such as wood, stone, earth can be crafted to exquisite levels of beauty. Natural grain and patterns accentuate designs.
	Biophilia – because of their non-toxicity, beauty, natural patterns, and “raw” quality, natural materials greatly enhance biophilic design.
	Material transparency – There are no added chemicals or ingredients.

Table 2: WELL categories and the ways natural building can help comply.

have been largely rural, the scale of the work has urban applications.

Earth construction in Western China

Traditional cave dwellings have been reimagined and modernized in Western China (figure 4). These use traditional materials and vernacular passive solar techniques with modern aesthetics andwindows to greatly reduce the use of coal for heating in this cold climate (Yang, Liu and Bainbridge 2015).

Urban placemaking using natural materials

City Repair (Portland, Oregon, USA) creates community through grassroots placemaking. They reclaim public right of way for gathering spaces and public amenities (Figure 5). This work has led to wide-ranging natural building activity in Portland and elsewhere (Hemenway 2015). City Repair founder and architect Mark Lakeman has pioneered the use of natural building in urban projects in the Pacific Northwest. These projects also often incorporate recycled elements.

Visionary projects in Italy

Several Italian architects have created bold new visions with extensive use of trees and other living plants integrated into the structures (Boeri Studio 2014). The buildings themselves are largely of conventional materials, but shows how artistic regenerative building ideas in cities are increasingly popular.

Natural building in developing cities

Developing world cities are the fastest growing (Blackburn-Dwyer 2016). Transformations of slums are needed to preclude social unrest and environmental disaster. These environments demand

could be part of a strategy to create structures that are local, healthy and affordable. These cities could be "labs" for innovative approaches. However, revitalization and rebranding of vernacular techniques are needed due to the wholesale abandonment of traditional building methods in most countries where these cities are located.

Builders Without Borders (BWB)

BWB (www.builderswithoutborders.org) is a non-profit organization with the mission to facilitate the building of sustainable shelter in places of need. An example of their work is in Nepal, where in 2015 earthquakes destroyed more than 750,000 homes. BWB has created a simple strawbale house design that uses local materials, provides high seismic resistance, is affordable and provides high thermal insulation. BWB is in the process of government approval and access to government funding. BWB is also working with the Bishwa Seva organization and the NewSchool of Architecture + Design to create a teacher training center and demonstration site for sustainable local construction.

Haiti

Figure 4 : A modernized "cave dwelling" in Western China using compressed earth blocks and passive solar design for improved interior comfort and reduced fossil fuel use.

There is the need for different approaches after the earthquake, flooding, and shameful redevelopment failures in recent years. Small-scale efforts using waste fiber, trash and rubble have shown some promise.

South Africa

The author has studied and promoted sustainable construction techniques in South Africa for over 20 years. This work has mostly occurred in rural areas, but some ideas are making it to urban environments, particularly straw-bale and earthbag construction. There is also some interest is stabilized earth blocks in peri-urban areas (Kennedy and Perry 2014).

The Auroville Earth Institute (AEI)

AEI has developed sophisticated CEB techniques, including woodless roofs. They have successfully disseminated their ideas around the world. Their buildings feature advanced water catchment, natural ventilation, and other regenerative features. AEI has built multiple-story buildings with this technique (Smith and Maini 2015).

La Voute Nubienne

This non-profit organization (www.lavoutenubienne.org) promotes woodless earthen construction in the Sahel region of Africa. They have had great success with their innovative earthbuilding strategies through innovative teacher-training and economic strategies.

THE FUTURE

Much more research into the utilization of natural materials in urban construction is needed, with a special need to educate builders and architects about the techniques. Challenges include how to deal with negative attitudes toward natural building systems, risk, codes and zoning, and technical issues. Some visionary strategies could be game-changers, including mass wood projects (also known as cross-laminated timber), full-scale 3D printing using natural materials as

Figure 5: An example of community placemaking in Portland, Oregon. It has been shown that such interventions have positive social impacts in neighborhoods that host these small public spaces. Photo credit: City Repair.

feedstock, and new natural materials (such as mycelium-based insulation) derived from biomimicry. This initial survey indicates, however, that natural building can be part of new urban planning solutions for human, societal and planetary health.

REFERENCES

Baker-Laporte, Paula, and Robert Laporte. 2015. The EcoNest Home. Gabiola Island, BC: New Society Publishers.

Blackburn-Dwyer, Brandon. 2016. “Where are the World’s Fastest Growing Cities?” Global Citizen. July 11. Accessed October 30, 2016. https://www.globalcitizen.org/en/ content/world-fastest-growing-cities/.

Boeri Studio. 2014. “Vertical Forest.” Stephano Boeri Architetti.Accessed October 30, 2016. http://www.stefanoboeriarchitetti.net/en/portfolios/bosco-verticale/.

Brisebois, Robin. 2016. The 5 S’s. Performed by Robin Brisebois. NewSchool of Architecture + Design, San Diego. September.

Crews, Carole. 2015. “Earth Plasters and Alis.” In The Art of Natural Building, by Joseph Kennedy, Michael Smith and Catherine Wanek. Gabriola Island, BC: New Society Publishers.

Crimmel, Sukita, interview by Joseph Kennedy. 2016. (September 6).

De Felippi, Francesca. 2006. “Traditional architecture in the Dakhleh Oasis, Egypt: space, form and building systems.” PLEA2006 - The 23rd Conference on Passive and Low Energy Architecture. Geneva.

DeBoer, Darrel. 2015. “Bamboo Construction.” In The Art of Natural Building, by Joseph Kennedy, Michael Smith and Catherine Wanek. Gabriola Island, BC: New Society Publishers.

Fisk, Robert. 2012. “Syria’s Ancient Treasures Pulverised.” The Independent, August 4. Accessed October 30, 2016. http://www.independent.co.uk/voices/commentators/fisk/robert-fisk-syrias-ancient-treasures-pulverised-8007768.html.

Hemenway, Toby. 2015. The Permaculture City. White River Junction, Vermont: Chelsea Green Publishing.

International Code Council. 2015. “Appendix S Strawbale Construction.” International Residential Code. Accessed October 30, 2016. http://codes.iccsafe.org/app/book/content/2015-I-Codes/2015%20IRC%20HTML/Appendix%20S.html.

International Living Future Institute. 2014. “Living Building Challenge 3.0.” Accessed October 30, 2016. https://living-future.org/sites/default/files/reports/FINAL%20 LBC%203_0_WebOptimized_low.pdf.

International WELL Building Institute. n.d. WELL Buildilng Standard. Accessed October 30, 2016. https://www.wellcertified.com/well.

Kapfinger, Otto. 2015. “Use the Earth! The Life and Work of Martin Rauch.” In Martin Rauch: refined earth construction & design with rammed earth, by Marko Sauer, edited by Otto Kapfinger and Marko Sauer. Munich: DETAIL - Institute fur internationale Architecktur-Dokumentation GmbH & Co. KG.

Kennedy, Joseph, and Adam Perry. 2014. “Catalytic Design Approaches for the Informal Sector to Improve Shelter in Rural South Africa.” Proceedings of the XXV International Union of Architects World Congress: “Architecture Otherwhere”. Durban: IUA.

Kennedy, Joseph, and Janine Bjornson. 2015. “Remodeling with Natural Materials.” In The Art of Natural Building, by Joseph Kennedy, Michael Smith and Catherine Wanek. Gabriola Island, BC: New Society Publshers.

Kennedy, Joseph, Michael Smith, and Catherine Wanek. 2015. The Art of Natural Building. Second. Gabriola Island, BC: New Society Publishers.

Magwood, Chris, interview by Joseph Kennedy. 2016. (September 6).

Onyegiri, Ikechukwu, and Joseph Diogu. 2013. “Evaluative Study of Earth Constructed Residential Buildings in Abia and Imo States of Nigeriia.” Proceedings Earth USA 2013 7th International Earthbuiding Conference. Santa Fe: Adobe in Action.

Guillaud, Hubert, and Thierry Joffroy, . 2016. “Preprints Terra2016.” Terra2016 XIIth World Congress on Earth Architecture. Lyon: Editions CRAterre.

Racusin, Jacob Deva, and Ace McArleton. 2012. The Natural Building Companion. White River Junction, Vermont: Chelsea Green Publishing.

Smith, Hillary, and Satprem Maini. 2015. “Building with Earth in Auroville.” In The Art of Natural Building, by Joseph Kennedy, Michael Smith and Catherine Wanek. Gabriola Island, BC: New Society Publishers.

Smith, Michael. 2015. “The Case for Natural Building.” In The Art of Natural Building, by Joseph Kennedy, Michael Smith and Catherine Wanek. Gabriola Island, BC: New Society Publishers.

Steen, Bill, Athena Steen, and David Bainbridge. 1994. The Straw Bale House. White River Junction, Vermont: Chelsea Green.

Urban Land Institute. n.d. Building Healthy Places. Accessed October 30, 2016. http://uli.org/research/centers-initiatives/building-healthy-places-initiative/.

2015. “Urban Straw Bale Solutions in Europe.” ESBG 2015. Accessed October 30, 2016. http://esbg2015.eu/category/inspiration/.

Wanek, Catherine. 2010. The Hybrid House. Gibbs Smith.

Welch, Kindra, interview by Joseph Kennedy. 2016. (August 29).

Yang, Liu, Jiaping Liu, and David Bainbridge. 2015. “Improving Vernacular Housing in Western China.” In The Art of Natural Building, by Joseph Kennedy, Michael Smith and Catherine Wanek. Gabriola Island, BC: New Society Publishers.