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Building tomorrow: A sustainable future starts in the classroom

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ABSTRACT: This paper addresses the critical need for educational infrastructure in Uganda and the sub-Saharan Africa, and seeks to promote sustainable design solutions to fulfill this need. The research compares local, traditional means of building with more contemporary, universal approaches, from specific construction infrastructure materials and methods to principles of design. The authors recognize that an evaluation of sustainable built infrastructure must consider impacts beyond an individual structure's environmental burden, but must also consider social, cultural and economic impacts, as well. Preliminary outcomes of this study and the design recommendations that follow are focused on evaluating and achieving durability and building performance while maintaining the critical connection between cultural, economic, and environmental sustainability.

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1. INTRODUCTION

1.1 The Need for Well-Built Schools

Despite a 67% gain in enrollment between 1999 and 2008, 69 million school-aged children across the globe did not have access to an education. Nearly three-quarters – or 31 million – of these children reside in sub-Saharan Africa. Organizations like the United Nations' Global Development Programme (UNDP) report that an inadequate number of teachers and a lack of proper educational facilities remain barriers to achieving Universal Primary Education (UPE) in the region. In Uganda, where enrollment rates have increased sharply over the last fifteen years, nearly 5,000 new classrooms would have to be built annually in order to accommodate the country's school-aged children and achieve the goal of UPE by year 2015. Only half as many schools to meet that benchmark are built each year. Meanwhile, over 50% of Uganda's population is under the age of fifteen; and while 54% of these children will finish primary school, only 20% will go on to attend secondary school. In the Wakiso District, Uganda's Minister of Education reports that 80% of first graders drop out of school, a statistic that might be significantly reduced, as the World Bank reports, if students in the country's most under-served regions had access to *well-built* schools.

1.2 What Does a Well-Built School Look Like?

Recognizing the very real and unsustainable challenges of the current demands for educational infrastructure in sub-Saharan Africa alongside mounting pressure on global resources, how do we proceed most quickly and responsibly to build the best possible schools to serve the communities in greatest need – both now and in the future? What are the best building practices, the best materials, methods of assembly, and principles of design that, when implemented, will lead to the most effective construction of this critically needed, durable infrastructure?

This paper will present the authors' research of both universal and local, site-specific construction methods, materials, and principles of design (as part of the Green Scale Research Project at the University of Notre Dame) related specifically, in this work, to a series of schools recently constructed in Uganda by the Indianapolis-based (USA) social-profit organization, Building Tomorrow. Using the structures recently executed by Building Tomorrow and the materials, methods and principles of design most commonly employed in the Building Tomorrow academies, our analysis focuses on evaluating, measuring, and comparing various approaches for confronting and solving common design challenges in this region, like proper orientation and siting, material sourcing, durability of details, and building security. The research involves whole building design analysis, from the bioclimatic forces that broadly influence building location, orientation, and building performance, to the composition of primary building assemblies – foundation, walls, roof, and openings – construction details, and other site-specific considerations.

In addition to qualitative analysis, our research is specifically focused on empirically evaluating and comparing known ways of making – what they are and why they came to be – in order to best assess how local, traditional materials and methods compare to universal, contemporary approaches. (For this, we utilize the GreenScale, a modified LCA method under development by the authors to perform a comparative analysis of building materials, including their specific material properties, thermal performance, material embodied energy and embodied water, site impact and costs associated with long-term maintenance and recurrent embodied energy.)

1.3 Suggesting a sustainable rather than a prescriptive approach
This research recognizes that when it comes to sustainability, whatever are to become our models for building, it is critical that we fully understand and pursue the best possible – and most durable (both culturally and ecologically) – solutions. Accordingly, the aim of this research is to generate a guide of best practices for the design and execution of new, sustainable education facilities in Uganda. While these recommended "best practices" the outcome of the ongoing research and analysis described here, they are not intended to become a set of prescriptive rules, but rather a tool to enable the best possible outcome: the expansion of sustainable educational infrastructure throughout sub-Saharan Africa. If we accept that building sustainably means using building materials and methods that collectively have less of an impact on the environment, and that the full impact of what we build is measured over time, this research intends to advance model practices for building responsibly and durably in order to meet the present needs of individual communities while anticipating the future demands of a growing and promising population.

This research readily acknowledges the precedent for guides, such as this one, that promote "best practices"; certainly numerous international and external NGOs have produced building-infrastructure-related documentation that provide such recommendations. Where this research departs however, is at the critical intersection of environmental impact and cultural feasibility, and the importance of localized decision-making over the application of generalized recommendations, aspects that are often missing in the aforementioned guidelines. For example, oftentimes, when generic, "international" building solutions are provided, the individuals that actually implement building plans will depart from these recommendations, favoring local building customs over unfamiliar, prescriptive guidelines. Predictably, these aforementioned building codes or manuals typically include a similarly generic recommendation: "use local information and expertise." (EMI 2007) This research aims to do just that—and meanwhile acknowledge the value of evaluating and codifying the "best practices" from current building practices in sub-Saharan Africa, so that future generations may benefit and learn from educational infrastructure that is durable and site-responsive - to environment, place, and culture - over time.

2. PRELIMINARY FINDINGS

While contemporary methods of building performance analysis are focused largely on the thermal performance of conditioned buildings, such as the insulating properties of the envelope systems, methods of construction throughout Uganda and sub-Saharan Africa are arguably much simpler, in terms of program and scope, than such larger and conditioned structures. Therefore exhaustive quantitative comparison of assembly thermal performance is not as immediately pertinent in this study. Rather, it is at the critical intersection of long-term environmental impact and social and economic feasibility that this research approaches the analysis of specific building design solutions and their relative sustainability. Preliminary results of our ongoing research follows:

2.1 Wall Systems: novel earth compression technology and more traditional means
Interlocking Stabilized Soil Bricks (ISSBs) is a compressed earth masonry product that is gaining traction as a primary building envelope component in Uganda and in other developing nations. As with any emerging technology, it is imperative that any potential broader impacts of this technology on the environment are studied and understood. While the production of ISSBs requires no firing and the bricks are largely made from soil found on-site (thus each brick has virtually no embodied energy tied to transportation or fossil fuel related manufacturing processes wiith the exception of the embodied energy tied to cementitious stabilizing agent), building construction involving ISSBs is more involved, in terms of construction sequence and duration, than other traditional masonry materials used in this region. Compressed earth masonry units are produced manually, typically using a single-brick press machine (for bricks made in Uganda, the closest source for the brick press is Kenya). As the technology has gained traction in the region as a novel and popular building method, literature is emerging about the performance and implementation of the blocks.

Figure 1: Vernacular fired brick masonry technique *(Esteban, W. May 2010)*

Because the bricks are typically made on-site via manual, rather than mechanical processes, ISSB boasts little to zero embodied energy (not accounting for any energy related to the transportation of aggregate, binding material, water, workforce, or press). (Not using kilns means also not using fuels, like wood, which is particularly challenging in countries, like Uganda, with significant deforestation.) With its interlocking design, the ISSB technology is also promoted as eliminating a significant amount of cement-based mortar over other, local masonry techniques, pictured below (see Figure 1), where the ratio of mortar to fired clay brick is typically generous in the region. Joint detailing is not just a matter of aesthetics; the long-term durability and structural stability of a masonry building can be greatly impacted by the manner and consistency of making joints. (Allen and Rand 2007) ISSBs, or similar air-dried compressed earth masonry technologies, in their production and laying, are not without concern: as the soil composition of the bricks is chiefly from on-site sources, there is a significant amount of variation in the stability of the raw material, even as Uganda and other nations in the region boast generally acceptable, and likewise accessible, deposits of murram, the recommended sub-soil material for ISSB production (Deboucha and Hashim 2007). Additionally, utilization of ISSBs in community-driven construction projects poses unique labor challenges. Unlike precast fired masonry units, the manual labor required to produce an ISSB brick is intensive, and from anecdotal accounts it seems a task nearly exclusively suited to men. These accounts from Building Tomorrow do not align with perhaps more optimistic expectations about productivity from brick press manufacturers. In rural Ugandan villages, labor is not traditionally subdivided by gender. However, according to Building Tomorrow reports, the use of ISSB bricks dichotomizes tasks and disrupts the traditional division (or absence of) labor on the construction site. This, in combination with the additional time needed for sun-curing the bricks results in extended construction time, as compared to traditional, precast masonry units. To address structural concerns related to compressed earth masonry, structural columns or buttresses of ISSB can be employed. Where Building Tomorrow has employed designs that have been carried out without the knowledge that ISSB technology would be used, on-site changes to designs have had to be made to accommodate the structurally-advisable addition of buttresses. For efficiency of both time and resources, the full wall system should be determined wherever possible at the outset of the design process. As for issues related to the duration of construction and the division of labor, Building Tomorrow recommends the development of a strategic plan to guide both brick production and construction.

	Embodied Energy/unit	Case Study Total	Cost (Ugx)	Average building total	Mortar considerations	Sourcing	Cultural Ramifications
Fired Clay Brick *Produced via conventional fired brick means*	4.25 MJ/brick	106,250 MJ	150/brick	3,750,000 UGX	Conventional mortar technique is more liberal than western masonry standard proscribes.	Small-scale brick manufacturers throughout rural Uganda.	While fired brick is not as prevalent in residences as wattle-and-daub, it otherwise stands to be most prevalent wall system otherwise in rural Uganda.
Compressed Earth Masonry Unit *Produced using manual press; products like Interlocking Stabilised Soil Bricks*	Virtual Zero*	Virtual Zero	Press 2,485,000, Cement 23,000/bag	3,083,000 UGX	Mortared every other course; 5 mm. When carried out by local craftsmen, however, more liberal mortar application is not unusual.	Nearest press manufacturer located in Kenya.	Labor divisions along gender lines.

Figure 2: Fired Clay Brick vs. Compressed Earth Masonry Unit

Although our preliminary findings and numerous recent external studies on the ISSB technology indicate that the system as a viable option for durable construction in Uganda, implementation guidelines published by external organizations, like the United Nations, recommend "intense supervision" on building projects that involve ISSB (ISSB: Appropriate Earth Technology in Uganda 2009). These provisions lead to questions regarding the role and authority over non-local building technology implementation. Beyond concerns about the structural uniformity – and therefore, durability – of site-cast ISSB, assimilation of the material into the local building culture is an equally important factor for determining the viability – and therefore, sustainability – of this emerging technology.

The comparison between contemporary compressed earth masonry like the ISSB product and traditional fired clay brick is common in temporary discourse. There are also studies that involve indigenous, traditional wall systems, such as wattle-and-daub and adobe. Using a developed metric that takes into account social, environmental and economic factors, T. Sanya asserts that these "more traditional" wall systems of Uganda, namely wattle-and-daub and adobe, are the most sustainable (Sanya 2007). Missing from Sanya's comprehensive study of Ugandan wall systems and their sustainability, however, is any discussion of long-term durability. If one's definition of "sustainable" simply means the ability to be sustained, in this case, as a practice (but not as a physical entity), wattle-and-daub certainly meets that designation, but is the method and material durable enough to meet the demand for permanent, reliable structures for the region's interminable educational needs? Building sustainably cannot simply studying and mitigating environmental impact related to long term durability without considering social impacts, and likewise cannot simply look at social considerations without the environmentally-motivated concern for long-term durability.

2.2 Local Materials: Use and sourcing of timber and its alternatives

In much the same way, our research studies the broader implications of traditional timber construction versus metal construction in Uganda, and considers the prevailing perception of wood as an unfeasible building material, particularly domestic sources. Analysis of early designs for Building Tomorrow reveal a u-shaped building footprint with an excessive roof structural design. Later iterations sought to reduce the overdesigned superstructure with increased use of metal. Similarly, while no Building Tomorrow Academy has yet incorporated glazing in its openings, metal frames of sorts were utilized in a variety of cases, chiefly for security purposes (See Figure 3b). While steel per volume performs more efficiently than timber, the horizontality of the window design permitted for easy access into the classroom above the ring beam (incidences of theft did therefore occur) and because of its sourcing and customization, solutions, like these, are neither environmentally nor financially sustainable for the organization.

Figure 3a: Inefficient timber roof truss intersection; Figure 3b: metal door and transom; and Figure 3c: truss condition with local site-hewn timber. *(Esteban, W. May 2010)*

Studies reveal a vast inadequacy of research into indigenous species and the feasibility of their use, and with an increase in general and widespread education, more proper timber building could be encouraged, or at the very least, explored (Zziwa, Ziraba, and Mwakali 2009). At present, in rural areas where construction work is largely supported by external organizations, imported designs often call for dimensional lumber although when designs are implemented the structural material is often rough-hewn timber from the site, giving rise to ad hoc superstructure design changes during construction (See Figure 3c).

Per our analysis, energy costs associated with on-site felled timber are less than those of sawn and processed lumber or metal products. Since the superstructure of these education facilities is generally fairly minimal, considerations related to the transport of materials, local sourcing where possible, and the functionality of the materials used become primary concerns.

Site	Primary construction & design description	EE/unit	Other considerations
Kimomba	Dimensional, rough-sawn, timber	1.5 MJ/kg timber	Sourced local to site
Gita	Timber withsteel connections	1.5 MJ/kg, 35 MJ/kg	Sourced local to site
Lutisi	Site-felled timber	Virtual zero	Consistency of members, connections

Figure 4: Building Tomorrow superstructure cases

2.3 Construction Details

Even at the micro-scale can local site-specific design solutions be vetted alongside more universal counter-parts.

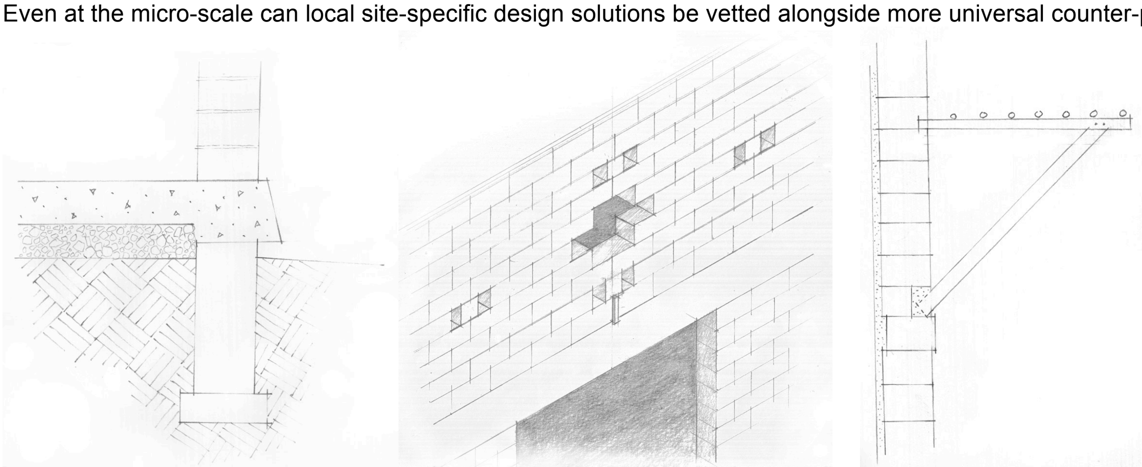

Figure 5a: Foundation condition for prevention of termite infestation; Figure 5b: omission of masonry units to allow for ventilation; and Figure 5c: One shading device design proposing use of local reed plant

Specific to Uganda and the region is the risk of termite infestation, and generic slab on foundation conditions simply do not address this risk. One local solution, depicted in Figure 4a, provides a ledge that is inaccessible to the local termite species like those in rural Kyeitabya.

When conventional clay fired brick is used as a wall system, it is common in the region to utilize compatible ventilation bricks in the transom zones above doors and windows to allow for cross ventilation. In instances where these locally-produced bricks are not compatible, such as with the ISSB system because of its interlocking profile, strategic omission of bricks in the transom and timber louvered treatment in the above-ring beam zone are commonly utilized design solutions.

Furthermore, in instances where small-scale shading devices seem suitable, local reed plants have been used to construct such devices, and these sorts of design solutions are best integrated into the design in the earliest stages of conception.

3. CONCLUSION

3.1 What does a sustainable school look like?

Many parallels can be drawn between sub-Saharan Africa's pressing need for educational infrastructure and post-disaster housing reconstruction efforts worldwide. These projects are oftentimes financed by the entities throughout the global community and typically executed by non-native external organizations. And like housing reconstruction efforts, school construction projects are most often characterized by an expectation for rapid speed of construction. Numerous reports on construction and reconstruction projects acknowledge the complexities of such efforts, and take into account both matters of ecological and logistic efficiency, and more importantly, perhaps, the cultural ramifications of different approaches to such rebuilding efforts (Miller and Rivera 2011, Barakat 2003, Barenstein 2006). While foreign-contractor-led approaches are oftentimes the most time-targeted means of reconstructing critical housing infrastructure in disaster-struck areas, there is growing concern about the physical and cultural impact of external influence. A trend supporting more participatory, resident-led reconstruction efforts, like those described in the reports of the Humanitarian Practice Network and Miller and Rivera's chronicles of reconstruction efforts, points to a growing agreement that "the key to success ultimately lies in the participation of the local community." (UNDRO 1986) The outcome of this ongoing research, a pattern book of best practices, intends to contribute to the growing discussion regarding local, site-specific solutions developed over time by the local community as the most sustainable means of building for the future. The research, grounded in both qualitative and empirical research, intends to provide this discussion with both qualitative and quantitative data on sustainable building practices in the region. In Uganda – and elsewhere in sub-Saharan Africa – building a sustainable future starts in the classroom.

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