The Sprouting Home

A modular housing design for low-income families in Western Kenya

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Problem Statement

With a population of 43M people, 45.9% of the Kenyan population lives below the poverty line[1]. In 2005 data, approximately 67% of the country was living on less than \$2 per day. The United Nations' Millennium Development Goals indicate the "eradication of extreme poverty" as the number one priority[2]. One way to accomplish this is to create jobs. The second way is to reduce the costs of goods to make a higher standard of living more affordable. We hope to improve housing conditions to support the latter.

Modular housing provides an expandable base from which to grow in small steps. By providing a repeatable and customizable base, a family would be able to purchase a house that would suit current needs and later be expanded to meet future requirements.

A successful design must be first safe and secure. It must also be appropriate for the culture, climate, and a few other exogenous conditions such as availability of construction materials. In analyzing these constraints, one health issue we found was the prevalence of Acute Respiratory Infections. ARI's cause approximately 3 – 5 million deaths, primarily of children under the age of 5. Another of the Millennium Development Goals is to reduce childhood mortality rates. We will also focus on constructing a modular component that will reduce the risks of ARIs.

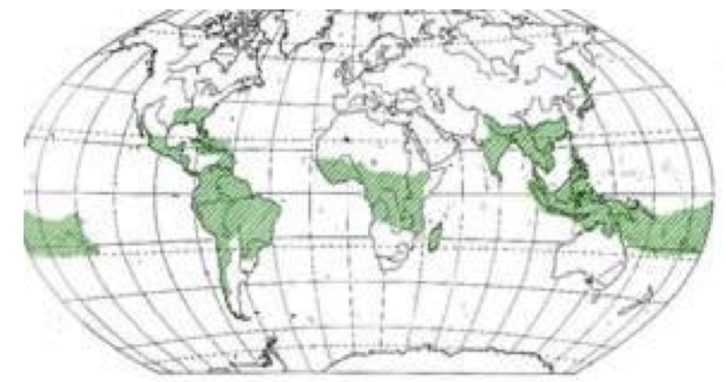
With these goals, we must provide an acceptable housing option. Our assumptions are that there is no electricity available, the land is already purchased, and the housing structure is one-story. We will be focusing on the humid climate region near Lake Victoria.

Idea Generation

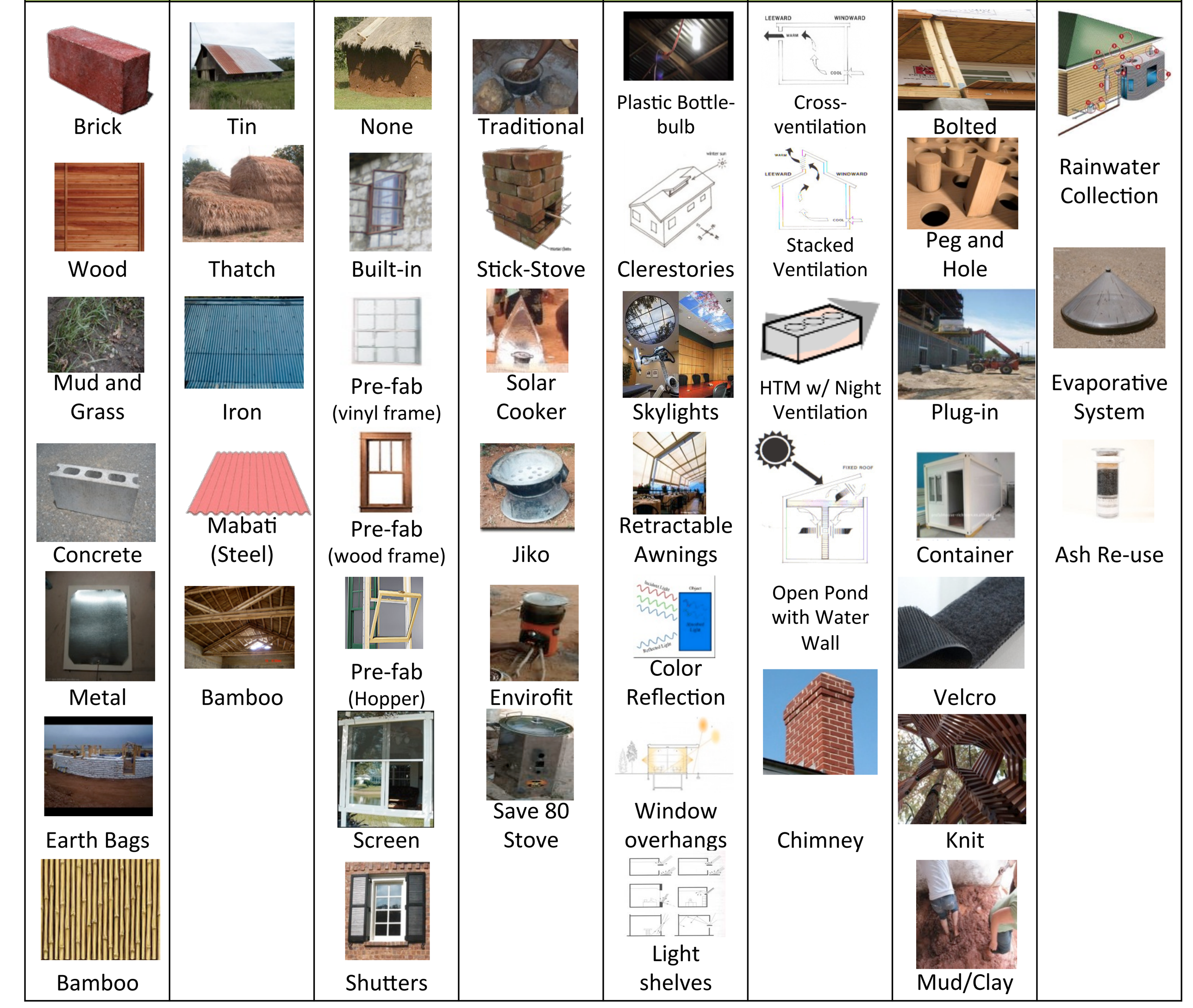
Idea generation takes many forms and can be accomplished individually or cooperatively. To motivate new ideas, morphological charts organize the systems available to comprise a dwelling in Kenya.

Morphological Chart

The Morphological Chart consolidates ideas in a visual manner. They are presented here under the system in which they would be used.



Areas of the world appropriate for growing bamboo



Wall Material	Roof material	Windows	Cooking Materials	Lighting	Ventilation	Connection and Assembly	Water Systems
Brick	Tin	None	Traditional	Plastic Bottle-bulb	Cross-ventilation	Bolted	Rainwater Collection
Wood	Thatch	Built-in	Stick-Stove	Clerestories	Stacked Ventilation	Peg and Hole	Evaporative System
Mud and Grass	Iron	Pre-fab (vinyl frame)	Solar Cooker	Skylights	HTM w/ Night Ventilation	Plug-in	Ash Re-use
Concrete	Mabati (Steel)	Pre-fab (wood frame)	Jiko	Retractable Awnings	Open Pond with Water Wall	Container	
Metal	Bamboo	Pre-fab (Hopper)	Envirofit	Color Reflection	Chimney	Velcro	
Earth Bags		Screen	Save 80 Stove	Window overhangs		Knit	
Bamboo		Shutters		Light shelves		Mud/Clay	

Concept Selection

TRIZ

TRIZ is a tool for the concept generation in the design state of any product that can be used to generate parameters and technical contradictions and to generate principles to create new ideas for each of the groups seen in the morphological chart. Many ideal final results (IFRs) were created in order to evaluate the parameters found in the technical contradictions of the morphological chart. These parameters were combined with each other to generate the principles, and 4 parameters were used for each IFR. Below, the ideal final result for ventilation systems is presented with the parameters, principles and new ideas generated.

IFR Example: "A passive cooling and ventilation design will eliminate the need for electricity used while providing a comfortable indoor air temperature by controlling air flows throughout the home."

This new idea was inspired by combining the different interests of all the groups to come up with new innovative ideas using the 40 design principles as a basis. The following table shows the parameters generated from the IFR as well as the combinations and the principles generated by the TRIZ matrix.

The principles generated by the TRIZ matrix that appear repeatedly were the ones considered in the idea generation. These were principles 10 (Preliminary Action), 15 (Dynamism), 35 (Physical or Chemical Properties), and 38 (Strong Oxidants). The following ideas were generated using principles 10, 15, 35, and 38, with the principle number shown in parenthesis:
Idea 1: High thermal mass with night ventilation (10)
Idea 2: Cross ventilation (15)
Idea 3: Radioactive and evaporative cooling (35)
Idea 4: Open pond with a water wall (38)

	Parameters	Combinations	Principles		
1	Speed [9]	1 & 2	2	15	35
2	Power [21]	1 & 3	16	35	38
3	Waste of Energy [22]	1 & 4	10	15	26
4	Adaptability [35]	2 & 3	10	35	38
		2 & 4	17	19	34
		3 & 4	A	L	L

QFD

Alternative	Description
Concrete - Luxury	Concrete Foundation, Bamboo walls, Bamboo Roof, 2 doors, windows with screens & shutters, Chimney, Stick-stove, Ceramic Jiko, Rain water collection, Ash reuse
Concrete - Regular	Concrete Foundation, Bamboo walls, Bamboo Roof, 2 doors, windows with shutters, Stick-stove, Rain water collection, Ash reuse
Wood - Luxury	Wood Foundation, Bamboo walls, Bamboo Roof, 2 doors, windows with screens & shutters, Chimney, Stick-stove, Ceramic Jiko, Rain water collection, Ash reuse
Wood - Regular	Wood Foundation, Bamboo walls, Bamboo Roof, 2 doors, windows with shutters, Stick-stove, Rain water collection, Ash reuse

COMPATIBILITY MATRIX

	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
Ceramic Jiko																						
Solar Cooker																						0
Stick-stove																					1	1
Shutters																				1	1	1
With Screen																			1	1	1	1
Sliding																		1	0	1	1	1
Mabati																	1	1	1	1	1	1
Bamboo (roof)																0	1	1	1	1	1	1
Knit															2	0	1	1	1	1	1	1
Plug-in														0	0	0	1	1	1	1	1	1
Peg and hole													1.5	0	0	0	1	1	1	1	1	1
Bolting system												0	0	0	0	1	1	1	1	1	1	1
Brick											0	0	0	0	1	0	1	1	1	1	1	1
Earth bags										0	0	0	0	0	1	1	1	1	1	1	1	1
Bamboo (walls)									0	0	0	1	1	2	2	0	1	1	1	1	1	1
Ash re-use								1	1	1	1	1	1	1	1	1	1	1	1	2	1	2
Evaporative system							0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
Rain water collection						0	2	1	1	1.5	1	1	1	1	2	0	1	1	1	1	1	1
Solar					1	1	1	1.5	1	1	1	1	1	1	1	0	1	1	1	0	2	0
Biomass				1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1.5	0	2
Windows			1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	2	2	2	1	2
2 Doors		1	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	2	1	1.5
Chimney	1.5	1	1	1	1	1	1.5	0.5	1	2	1	1	1	1	1	1	1	1	1	2	0	1.5

CONCEPTS: C1 Chimney, C2 2 Doors, C3 Windows, C4 Biomass, C5 Solar, C6 Rainwater Collection, C7 Evaporative system, C8 Ash re-use, C9 Bamboo (walls), C10 Earth bags, C11 Brick, C12 Bolting system, C13 Peg and hole, C14 Plug-in, C15 Knit, C16 Bamboo (roof), C17 Mabati, C18 Sliding, C19 With Screen, C20 Shutters, C21 Stick-stove, C22 Solar Cooker, C23 Ceramic Jiko

Compatibility Score

	FUNCTIONS:	Weights:	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23
F1	Minimizes First Cost	8	4	10	7	0	-10	4	4	0	10	10	1	4	7	10	10	7	4	4	1	4	7	5	7
F2	Maximizes Durability	6	10	10	7	4	1	7	7	10	10	7	10	10	4	7	7	7	7	4	1	4	7	1	4
F3	Minimizes Carbon Footprint	4	-4	10	10	10	4	7	7	7	10	4	-4	-1	0	0	0	8	-7	0	-1	-1	-7	4	4
F4	Maximizes Climate Appropriateness	2	0	7	4	0	7	7	10	0	10	10	-4	0	0	0	0	0	5	10	10	7	-1	1	7
F5	Maximizes Ease of Use	7	10	10	4	-4	7	10	10	-4	7	7	1	-1	4	4	-4	-4	9	-4	-1	1	4	4	-1
F6	Maximizes Obtainability	10	-4	10	-4	10	4	7	7	10	7	7	-4	-1	-1	-1	1	7	-4	-4	-1	-4	4	4	-4
F7	Maximizes Ease of Construction	5	-4	7	1	7	-1	4	4	7	7	10	4	4	7	7	10	0	7	4	4	7	7	4	10
F8	Maximizes Cultural Appropriateness	1	1	-1	10	7	4	7	4	4	1	1	7	4	7	4	1	7	10	1	10	10	7	1	4

Utility Theory

We employed the functional requirements for QFD as attributes to compute utility of alternatives derived from QFD. The following steps were performed to compute the aggregated utility values of the alternatives.

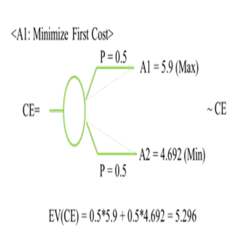
Dataset for Utility

	Minimizes First Cost	Maximizes Durability	Minimizes Carbon Footprint	Maximizes Climate Appropriateness	Maximizes Ease of Use	Maximizes Obtainability	Maximizes Ease of Construction	Maximizes Cultural Appropriateness
CL	4.69	6.77	3.31	3.92	2.15	2.69	5.15	4.92
CR	4.90	7.30	4.40	3.40	2.00	4.40	5.70	4.90
WL	5.46	6.46	4.08	3.38	1.62	3.00	4.85	5.23
WR	5.90	6.90	5.40	2.70	1.30	4.80	5.30	5.30

Single Attribute Utility

1. Choosing CE → 2. Computing RT, A, and B → 3. Utility Function

- Expected Value of Lottery



- $CE = LN\left[0.5\times e^{-\frac{Best}{RT}} + 0.5\times e^{-\frac{Worst}{RT}}\right]\times(-RT)$
- $A = e^{-\frac{Worst}{RT}} \div \left[e^{-\frac{Worst}{RT}} - e^{-\frac{Best}{RT}}\right]$
- $B = 1 \div \left[e^{-\frac{Worst}{RT}} - e^{-\frac{Best}{RT}}\right]$

- $U(x) = A - B\times\left[e^{-\frac{x}{RT}}\right]$

Multi-Attribute Utility

1. Scaling Factor → 2. Normalizing Factor → 3. Utility Function

- Choosing the most important attribute
- Lottery Problem for k of the attribute
- Relative Magnitude of other k

- $1 + K = \prod_{i=1}^{n}(Kk_i + 1)$

- $U(x) = \frac{1}{K}\left[\prod_{i=1}^{n}(Kk_iU_i(x_i) + 1) - 1\right]$

Single & Multi-Attribute Utility Results

	Minimizes First Cost	Maximizes Durability	Minimizes Carbon Footprint	Maximizes Climate Appropriateness	Maximizes Ease of Use	Maximizes Obtainability	Maximizes Ease of Construction	Maximizes Cultural Appropriateness	Aggregated Utility
CL	0.00	1.00	0.00	1.00	1.00	0.00	0.12	0.06	0.62
CR	0.00	1.00	0.17	0.83	0.95	0.40	1.00	0.00	0.78
WL	0.05	0.00	0.08	0.82	0.67	0.01	0.00	0.83	0.70
WR	1.00	1.00	1.00	0.00	0.00	1.00	0.23	1.00	**0.97**

→WR is the best design with the highest utility

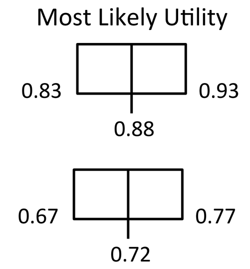
Game Theory and the Competitive Market

We assumed two artificial competitors to apply Game Theory. By assuming probabilities to select the concepts listed in QFD, we calculated competitors' utilities based on a previously determined utility function to choose a specific design.

Competitors

Disaster Dome – provides very low cost house which is easy to construct

Bridge Builders – provides very low cost and durable house



Player Disaster Dome

Player Sprouts			0.83	0.93
			T1	T2
	0.78	CR	(0.78, 0.83)	(0.78, 0.93)
	0.97	WR	(0.97, 0.83)	(0.97, 0.93)

Player Bridge Builders

Player Sprouts			0.67	0.77
			T1	T2
	0.78	CR	(0.78, 0.67)	(0.78, 0.77)
	0.97	WR	(0.97, 0.67)	(0.97, 0.77)

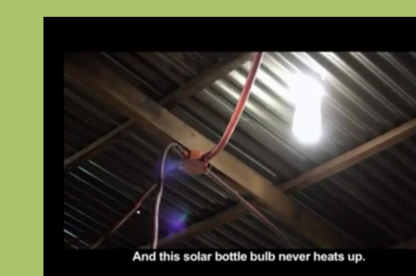
Nash Equilibrium

→ We should pursue WR whatever competitors do

Final Design

Bamboo Roof

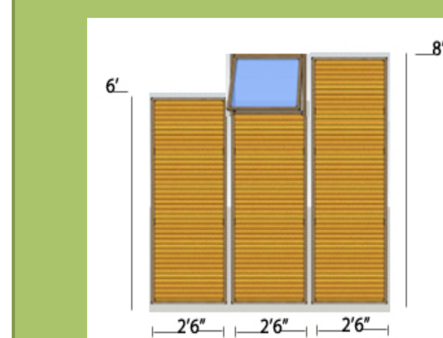
Two-Entrance Dwelling



Plastic Bottle Bulbs

Knit Connection

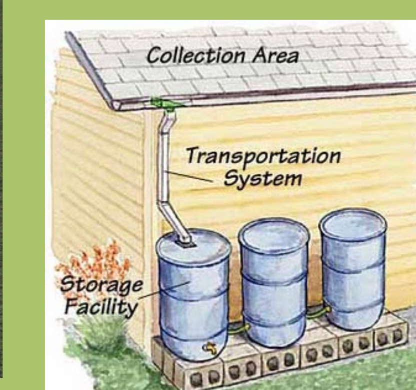
Plastic Bottle Bulbs, Construction



Bamboo Wall Panels

Single Unit Dwelling

Kitchen Unit with Chimney



Water Collection System

		Number of Units	Volume or Area		Cost/Unit	Total Cost	Labor Cost	Carbon Footprint (kg-CO2)
Foundation	Excavation	4	28.8	cubicft			\$4.00	
	Ax Head with Handle	4			\$6.00	\$24.00		
	Bow Saw	2			\$6.30	\$12.60		
	Hammer	4			\$5.00	\$20.00		
	Wood Piles	2	57.6	cubicft	\$6.00	\$12.00		15.7
		2	48	cubicft	\$5.00	\$10.00		
	Wood-Tar Creosote	1	100	oz	\$1.00	\$1.00		
Slab	Wood Frame: Bearers	7	28	cubicft	\$3.10	\$21.70	\$10.00	480
	Wood Frame: Joists	6	6	cubicft	\$0.78	\$4.65		
	Bamboo Flooring	10	10	sqft	\$2.00	\$20.00		796
Exterior Wall	Wood Frame	9	0.6912	cubicft	\$1.86	\$16.74	\$20.00	16.8
		3	0.3072	cubicft	\$2.48	\$7.44		
		2	0.2560	cubicft	\$3.10	\$6.20		
	Bamboo Panels	13	195	cubicft	\$3.00	\$39.00		37.92
		3	60	cubicft	\$4.00	\$12.00		
	Bamboo Truss	2	20	sqft	\$6.00	\$12.00		480
	Connectors (Knit w/Rope)	1	80	ft	\$0.50	\$0.50		
	Windows	1	5	cubicft	\$2.50	\$2.50		408
	Nails	50			\$0.02	\$1.00		
Interior Finishes	Recycled Plastic Bottle Bulbs	2			\$1.00	\$2.00	\$0.50	
Roof	Bamboo Shingles	12	12	sqft	\$3.00	\$36.00	\$15.00	277
	Rafter	2	0.3072	cubicft	\$3.72	\$7.44		
	Rainwater Collection System	1			\$5.00	\$5.00		
Water Storage System	Barrels	1	42	gal	\$4.00	\$4.00	\$1.00	5.25
Insect Prevention	Mosquito Nets	2	5	sqft	\$0.40	\$0.80	\$0.50	1.26
	Planting (Cymbopogon)	4			\$1.25	\$5.00		
Cooking System*	Stick Stove (Brick)	28	0.7973	cubicft	\$0.13	\$3.64	\$5.00	3.49
	Chimney (Brick)	42	1.19595	cubicft	\$0.13	\$5.46		5.24
*Indicating kitchenette module with additional materials and cost			Housing Module			\$283.57	\$51.00	2517.93
			Kitchenette Module			\$292.67	\$56.00	2526.66

Final Results

Family Cost: \$1,017.81
Carbon Footprint: 7,562 kg-CO_2

*includes 2 units + kitchen

References
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