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Plastic Bottles In Architecture: A How To Guide On Life-Cycle Through Reuse

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PLASTIC BOTTLES IN ARCHITECTURE

A HOW TO GUIDE ON LIFE-CYCLE EXTENSION THROUGH REUSE

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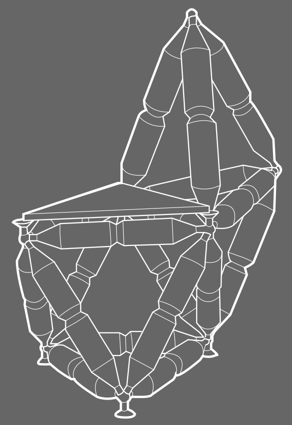
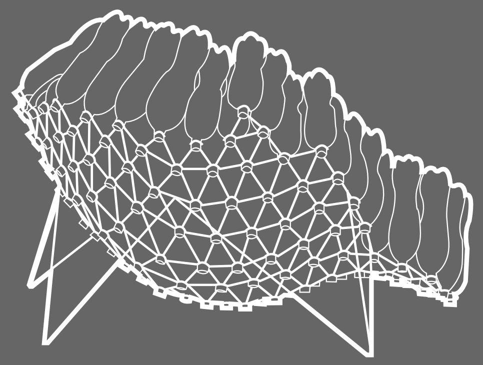
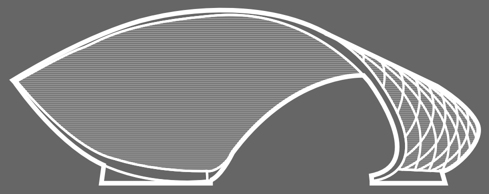
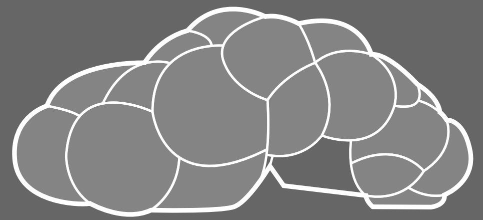
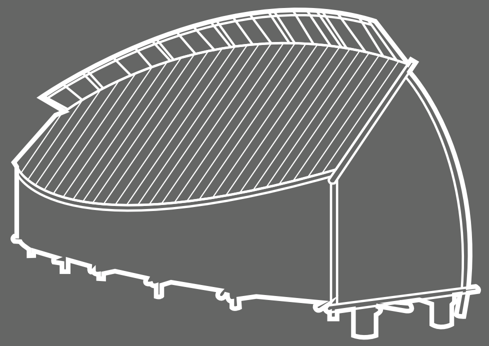
Fay Jones School of Architecture + Design
University of Arkansas - Spring 2022

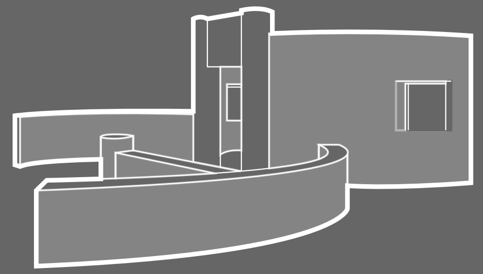












“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Contents

Introduction

Project Statement + Audience

This booklet represents a collection of 6 architectural case studies that reuse plastic bottles in a minimally modified way. The projects are analyzed and then broken down into a 'how to guide' using descriptive text, photos, and diagrams to demonstrate the construction practice. This guide is intended for any audience with a passion for sustainability to reproduce design tactics for creative plastic bottle waste management.

How are plastic bottles reprocessed in architecture? There are multiple facets of this inquiry that make it intriguing. Firstly, the potential to reduce plastic pollution is a compelling consideration due to the various environmental crises we are currently battling. The copious amounts of greenhouse gas emissions and plastic pollution we generate daily are unsustainable and endangering every ecosystem that it encounters. Reprocessing plastic bottles present opportunities for challenge, creativity, and resourcefulness within design. It calls attention to one's ethical values for stewardship, our place as humans within nature, and the responsibility for action one has regarding those beliefs. As peoples' destructive habits continue to impact the environment, the ability to ignore our ethical and moral responsibilities diminishes.

Why Care?

Stewardship is defined as the "conducting, supervising, or managing of something, especially the careful and responsible management of something entrusted to one's care."[1] The term is often used concerning human existence within the land in both religion and sustainability. Understanding stewardship of the land as a responsibility that each person possesses stems from one's concept of their place within the world, specifically their place within nature.

Across numerous cultures and theologies, a higher power commands people to care for the planet and to be stewards of the land. In the Christian Bible, Genesis 2:15 states, "The Lord God took the man and put him in the Garden of Eden to work it and take care of it."[2] In Aboriginal culture, the word 'Kanyini' means having responsibility and unconditional love for all of Creation.[3] The West African country, Ghana, has experienced a reclamation of religious values that promote stewardship through policy across its diverse community of Christian, Islamic, and indigenous African faiths. Those policies utilize "all the scientific knowledge of nature and associate it at the same time with the deepest insights of religious traditions about the place of man in the universe, his responsibility towards this world which s/he is now able to destroy but not to rebuild."[4]

Efficient stewardship is accomplished with the understanding that people are within their environments; they participate with direct influence because they are a part of that system, not apart from it. In terms of Gestalt theory and phenomenology, environmental phenomenology is a holistic view of a place where every piece is reciprocally related to each other.[5] To separate oneself from the natural environment is to say that their actions do not affect it. The "spectacular nature frame" perceives nature as a resource alienated from humanity. The current climate crisis that has developed globally is a direct consequence of that thinking. Human intervention has expedited climate change and pollution in a way that only a participant within an environmental system could accomplish. Humanity's one-sided dependency on nature and the exploitation of natural resources is an unsustainable mindset.[6] It is our ethical duty to treat other living beings with respect. Although, it is not enough to acknowledge that humankind is a part of nature. There must be an understanding of our place within that system. Our self-conceptualization as the center of the "frog pond" results in a hierarchy where people consume every natural resource we need and leave only what is left for the remaining inhabitants of the pond, both now and to come. People pollute our environment (our: the collective including those creatures outside of humanity) and recycle too little. Aldo Leopold suggests that we decenter ourselves for the collective well-being of "the pond" as a whole, the environment, and the creatures who share it.[7] It is selfish and self-destructive to blindly consume without replenishing what was taken. A sustainable existence ensures the viability of resources for the future.

Striving for sustainable cohabitation between people and the environment is the driving inspiration behind this inquiry. This is a discipline-oriented project analyzing the impacts of various case studies on triple bottom line sustainability while detailing the methods used to create them with the goal of replication by anyone. The design potential of plastic bottles for all aspects of sustainability, waste, and emissions reduction alone is significant enough to justify this research, regardless of the ethical potential it has for the audience.

Why Bottles? A Personal Testimony

When beginning this inquiry, I knew I wanted to investigate how waste management can occur within the field of architecture. I asked myself, "What kind of waste items do I produce the most of?" The question resulted in a list of single use plastics such as bags, utensils, packaging, hygiene products, bottles, and so on. To narrow my scope, I reflected on which of those products are the most likely to succeed when incorporated into architectural projects and decided to examine projects that utilize reuse practices rather than recycling exclusively. It is this process that led to a study of plastic bottles in architecture. Plastic bottles are structural, modular, and architectural in a design sense while simultaneously being a major contributor to the waste crisis. In the United States alone, more than 125 million plastic bottles are discarded each day, 80 percent of which end up in a landfill. This waste could potentially be diverted and used to construct nearly 10,000, 1200-square-foot homes (taking into consideration that it takes an average of 14,000 plastic bottles to build a home that size). Many believe this process could be a viable option for affordable housing and even help solve homelessness.[8]

Considering current statistics, the rate of plastic bottle consumption does not suggest a decrease in demand by the public. Due to this fact, the reprocessing of plastic bottles, either through reuse or recycling, presents a potentially great solution for the environment. The questions that remain to be pursued are: What has already been done? Why was it done (i.e. what purpose does it serve)? How has it been done? And how can the practice of reprocessing bottles in architecture continue in an accessible way for everyone?

Background

To fully understand how plastic bottles are reprocessed in architecture, it is important to understand each component and their relation to one another.

Reprocessing

Reprocessing materials and energy are significant steps towards sustainable production life cycles and development. The most common definition of sustainable development is, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[9] It is also described as the avoidance of the depletion of natural resources to maintain an ecological balance.[10] Waste of any kind presents an issue for ecological balance, natural resources, and future generations, particularly when mismanaged. A common rule of thumb for sustainable waste management is to, Reduce, Reuse, and Recycle. Equally as important as each of the "3Rs", is the hierarchical order of each word and its reciprocal efficiency. Reduction offers the best solution because there are fewer resources (material and energy) being used to produce and dispose of said item. Reuse proposes the next best solution because it implies a minimally processed solution to creating a second life for an item. This means fewer resources are used towards the end of the product's life cycle. Last is recycling, and while this is still a preferable option to the landfill or incineration for energy recovery, it requires a full reprocessing of the item, such as melting or grinding, to recover resource materials. Recycling requires additional resources to those used in production. Although the industrialized reuse and recycling of plastics is a beneficial process for the reduction of waste, much of the total plastics produced evade these stages and invade various ecosystems around the globe.

Waste management of plastic products is an increasing dilemma illustrated by the following statistics. On average, single-use plastics account for 40% of plastic produced every year, and every year 8 million tons of plastic waste escapes into the oceans from coastal nations. That is the equivalent of setting five garbage bags full of trash on every foot of coastline around the world.[11] It is estimated that by 2050 the ocean will contain more plastic by weight than fish."[12] Nearly 700 species, including endangered ones, are known to have been affected by plastics; most deaths are caused by entanglement or starvation, but sometimes plastic waste gets lodged in their digestive tract with reduces the urge to eat resulting in starvation. Microplastics are virtually impossible to recover.[11] They can absorb chemicals and are then eaten by animals, such as fish, who are harvested and consumed by humans. It is estimated that people who regularly eat seafood ingest up to 11,000 tiny pieces of plastic each year."[12]

The plastic production industry not only creates great amounts of waste but also results in large amounts of CO2 emissions and energy consumption. About 4% of global oil and gas production is used as raw material for plastics, and an equivalent percentage is used as energy during manufacturing. Due to the durability of plastic, many of these products accumulate in landfills and natural habitats. Approximately, 50% of plastics are used for single-use disposable applications, including but not limited to disposable consumer items such as beverage bottles.[13] According to the EPA, landfills received 26.8 million tons of plastic in 2017.[14] In that same year, about 14.5 million tons of plastic containers and packaging were generated. It was estimated that the recycling rate for PET and HDPE bottles in 2017 was 60.1% of that generation.[15] This means that 39.9% of PET and HDPE bottles were not recycled.[16] The use of recycled plastics in place of virgin materials directly reduces oil usage, emissions of greenhouse gases, and waste which are all characteristics of the global climate crisis. A study by the Department of Environment and Conservation (NSW) 2005 found that PET bottle recycling reduces landfill and net energy consumption. "A recent LCA (life cycle analysis) specifically for PET bottle manufacture calculated that use of 100 percent recycled PET instead of 100 percent virgin PET would reduce the full life-cycle emissions from 446 to 327 g CO2 per bottle, resulting in a 27 percent relative reduction in emissions (WRAP 2008e).[13]

Triple bottom line sustainability is composed of three pillars: environmental, economic, and social sustainability. Each pillar functions as a standard to ensure the survival, quality, and efficiency of their respective category. The moral of this philosophy is that society, the environment, and the economy are intrinsically connected. No real progress can be made by isolating one group. Recycling can stimulate the economy through collection programs; for example, companies purchase used products from consumers instead of virgin materials thus saving money and partially reimbursing consumers. It also offers saving opportunities for consumers who no longer need to purchase new products because of their reuse habits. Socially, the utilization of reprocessed material often offers solutions for marginalized people through advocacy and awareness along with building and fabrication.

Bottles

People started widespread use of soda bottles in the 1800s. These resembled alcoholic beverage bottles with their short stature and square bottoms. As the 1800s progressed, the design of soda bottles evolved with the Saratoga style, which resembled wine bottles, and the "blob-top" which created a secure seel to preserve flavor and carbonation.[16] In 1872, Hiram Codd designed the Codd-neck bottle for carbonated soft drinks.[17] After the foundation of the Coca-Cola company in 1915, the next evolution was created with the hobbleskirt bottle. The signature curves and contours of its design made it a staple of the brand, one that other companies attempted to mimic to increase sales. The customized bottle design has become a prime marketing technique for soda companies to set their brand apart.[18]

Nathaniel Wyeth patented the first successful plastic bottle in the 1970s when he utilized PET, polyethylene terephthalate, for bottle production because of its resiliency to carbonated drinks.[11] It was not long after this that plastic bottles were being utilized for water as well as soda by brands like Perrier, Evian, PepsiCo (Aquafina), and Coke (Dasani).[16] Different plastic resins that correlate with their size and usage make up the bottles. PET is used in soft drinks and water bottles whereas HDPE, or high-density polyethylene, is used in milk and water jugs because it is more durable and is necessary for these significantly larger containers.[16]

Since the 1970s, plastic bottle production, consumption, and ultimately waste, increased exponentially. Bottled water consumption in the United States alone has grown by 284 percent from 1994 and 2017.[16] Globally, over 1 million plastic bottles are sold every minute, and here in the US, only 30% are recycled.[16] Particularly in terms of waste, nearly "14% of all litter comes from beverage containers. When caps and labels are considered, the number is higher."[19] This is a troubling statistic considering that it takes at least 450 years for a plastic bottle (specifically PET) to completely degrade.[16] Plastic waste is detrimental to any ecosystem, and when the quantity of waste that escapes into the environment is considered, its effect becomes catastrophic for wildlife, plant growth, and the overall health of the system. For these reasons, efficient waste management for plastic bottles is crucial; reprocessing has been proven to be a successful solution. But what happens after a bottle has been reused or recycled? What potential is in the bottle's afterlife? One possibility lies within the architecture and design disciplines.

Architecture

Understanding that plastic bottles should be reprocessed is step one. Determining how they should be reprocessed is step two. There has been a movement recently to discover second-life opportunities for plastic bottles in areas like fashion, technology, horticulture, etc. This research explores the potential that reused plastic bottles have in buildings and fabrication. The material and design properties of plastic bottles show their potential for a second life, or an extended life cycle, in various scales of architecture.

Plastic as a material has been used in architecture because of its relative affordability, structural capacity, customizability, and mailable nature. Historically, it served as a substitute for cladding panels, building blocks, window frames, light structural members, staircases, and smaller interior items.[20] With the progression of technology, the prospects of plastics in architecture have expanded even further including prefabrication, 3D printing, sculpture, and appliances. By acknowledging the usage of plastic in architecture, it warrants the question, can plastic used in architecture originate from non-virgin material sources with minimal processing? It is this question that influenced the compilation of six case study construction manuals demonstrating just how it can be accomplished.

Why Reuse vs. Recycling in Architecture?

The following research evaluates two means of extending the lifespan of plastic through the lens of architecture. This booklet examines bottles that are strictly reused in architecture with the assumption that it is a more accessible form of sustainable plastic waste management. Here, a reuse and a recycled method are compared through a question rubric to investigate which is truly more accessible to the general population and thus more viable regarding triple bottom line sustainability. The case studies in question are two versions of plastic masonry units. Example one is the initiative founded by a Kaduna-based NGO, Development Association for Renewable Energies (DARE), with the help of a London-based NGO, Africa Community Trust where collected plastic bottles are filled with sand and secured together as a masonry wall system. The second is Conceptos Plásticos (Plastic Concepts) which is a company that produces bricks by melting reclaimed plastic and forming it into a mold. The bricks are then hammered into place. The comparison of these two projects is to gauge the effect on social, environmental, and economic sustainability through their methods. Can this set of rubric questions be used to identify the pros and cons of comparable solutions to determine the most ideal option for those pursuing sustainability in architecture? The goal is to compare these case studies for social, environmental, and economic potential while creating a dialogue of questions that others may use to determine what the most sustainable option is in various situations.

Case studies

As mentioned, case study one is the plastic bottle house built in 2011 in Kaduna, Nigeria. The initiative was founded by a Kaduna-based NGO, Development Association for Renewable Energies (DARE), with the help of a London-based NGO, Africa Community Trust to help tackle the housing and waste crisis.[21] Nearly 20,000 bottles were collected from the garbage, streets, or eateries and used for the full structure. The bottles are selected by size then packed with sand, bound by string, and cemented in place with clay and mortar. They are earthquake, bullet, fire, and weather resistant while being 18 times stronger than regularly available bricks.[8] Due to the thermal capacity of the bottle bricks, the interior of the structure maintains a temperature of around 64 degrees Fahrenheit year-round.[22] After three stories the structure can no longer continue as a result of the weight of the sand-filled bottles. This building practice is about 1/3 the price of similar buildings due to the cost of materials and has a round design to emulate an African appearance.[23] DARE engages young unemployed Nigerians that are vulnerable to militant groups by recruiting them for bottle-fill training. The bottle house method created jobs for all kinds of people groups.[24] Nigeria has a housing deficit of 16 million and over 14% of Nigerians are homeless.[21] Just within the US, over 125 million plastic bottles are discarded daily. This waste could be used to construct nearly 10,000, 1200-square-foot homes using this method as a viable housing solution to homelessness.[8]

The second case study is Conceptos Plásticos (Plastic Concepts) which was founded in 2011 by Fernando Llanos and Óscar Méndez. Together they patented a system of bricks and pillars made from recycled plastics. At the start, resources were obtained from recyclers and factories that discard tons of plastic daily.[25] In 2018, a community in the Ivory Coast partnered with UNICEF to transform plastic waste into schools using the Conceptos Plasticos bricks. Around 1.6 million children don't attend school due to a lack of classrooms. Since then, 26 classrooms have been constructed, and a plastic brick factory was built locally allowing brick production from within the country. The bags that once littered the streets and landfills now have value resulting in widespread collection for brick production.[26] Conceptos Plasticos has stated, "Our social impact changes lives through social and economic power for women and youth collectors in developing countries. We implement an innovative program to stimulate collective labor pursuing safe working conditions and better pay: a sustainable way to build strong communities and an optimistic lifestyle." The company implemented an empowerment program for women heads of households and young collectors in vulnerable communities.[27] The plastic waste is collected and then melted and poured into molds similar to three-kilo clay bricks. The bricks are hammered into place like legos and can extend up to two stories high resulting in a structure that is insulative, fireproof, waterproof, and earthquake resistant. A unit that is around 40 square meters is about $6,800 which is significantly cheaper to erect than a standard building.[25] On the company's website they state, "The project has four pillars from which it builds the sustainable strategy. I. Contribute to poverty reduction through a new opportunity in the recycling market. II. Helping to minimize some of the causes of climate change. III. Facilitating educational opportunities as a tool for community empowerment. IV. Promote gender equity. The Way Methodology is based on three principles. Environmental, to promote the importance of recycling among communities and to work for environmental conservation. Social, to dignify the work of recyclers through good labor practices while empowering communities through education and new technologies for waste management. Economic, to promote community entrepreneurship and contribute to fair trade practices between recyclers and traders.[27]

The rubric questions were divided into the three sustainability realms. Each question had a response for both the DARE bottle house and Concepticos Plasticos plastic brick methods. The responses were then reiterated in a summary at the end of each question.

Outcomes and Recommendations

What does each project do in terms of social, economic, and environmental sustainability? The recycling option, Conceptos Plastico's plastic brick, is the most sustainable when considered post brick production. It can be made from more plastic products than the DARE bottle method and can be quickly mass-produced and marketed. The bottle method is not a product, but rather a service which makes it more difficult to market on a large scale. Both projects can be replicated with minimal training for assembly. Conceptos Plasticos has made more tangible strides toward community engagement with its structure program to empower women in the plastic supply chain, but that does not negate the youth outreach accomplished by DARE. The sustainability issues with the plastic bricks arise when the recycling step is considered. Where the bottle method can be replicated from scratch, the plastic bricks require factory production to repurpose the waste. This additional step reduces accessibility through the necessary cost, material and tool access, and recycling process expertise needed to create the bricks. This hinders the social and economic categories of the sustainability comparison. Lastly, the brick production results in added energy usage and emissions to recycle the plastic waste. Each case study is successful in terms of triple bottom line sustainability, but when compared to each other the DARE bottle method is the most viable option from start to finish.

Regarding social sustainability, both case studies demonstrate significant efforts for the consumers' well-being and the well-being of those engaging in the process. They provide housing and education structures for those in poverty. Engagement with the community is also important in the supply chains and construction processes. This is most present in Conceptos Plasticos's work with empowering women through the plastic collection. In this regard, they are more successful socially. That said, the fact that the brick method is not possible before factor production makes it less accessible to the public. Anyone can replicate the bottle method with a bit of training on the filling and laying process. The brick method on the other hand cannot be replicated from scratch due to the production needs of the product itself. That requires special equipment and training. Though after the brick is made and acquired, the building process is very simple.

Economically, both precedents offer opportunities for profits to be made on the resultant products and services. They even offer opportunities for the vulnerable communities to engage in the production system to further profit. The plastic bricks can be mass-produced, require less upkeep, and are viable in more climates than the bottle and mud method. These facts suggest a more marketable business, but for those that are to benefit from affordable housing, the extra production step results in a high cost. In the Nigeria example, the bricks were so successful that a factory was established locally which helps mitigate that cost some, but other locations would need to secure funding or donations to acquire the bricks for construction.

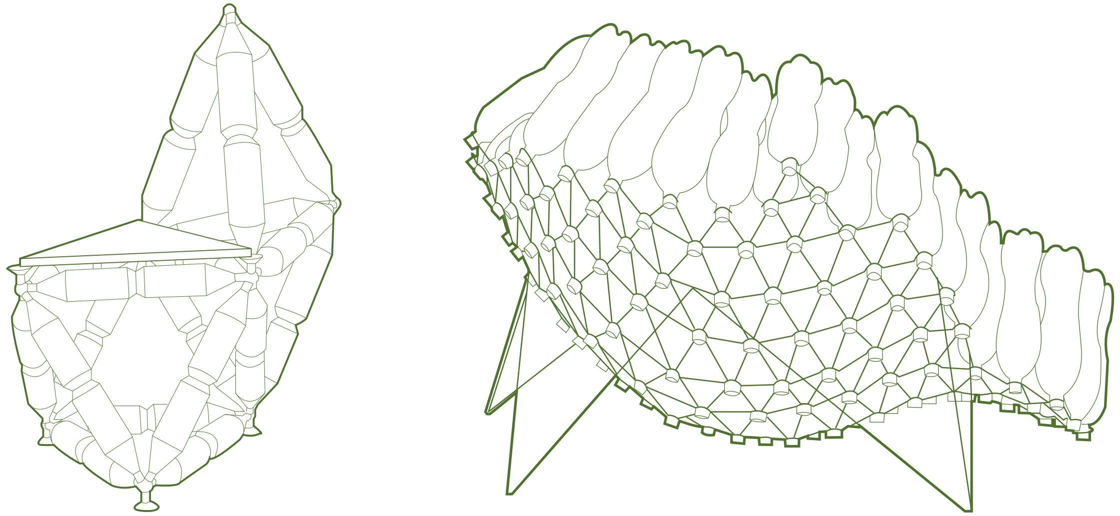
Each project demonstrates a positive alternative to diverting plastic waste from landfills, but the plastic bricks divert all forms of plastic, not just bottles. Because plastic is so durable, needing approximately 300 years to degrade, both structures will require little maintenance. The other materials included in the structures may need upkeep, but the plastic most likely will not. There is very little plastic waste created by the bottle method because the entire bottle is used and energy consumption would be composed of predominantly transportation emissions. Contrarily, the brick production process results in added energy usage and carbon emissions plus the need to transport the bricks. The machinery needed to produce the bricks add additional emissions when the production of the factory is included.

Potential implementation efforts in the future could include the acquisition of funding from charitable organizations for further housing construction by both the bottle house method and the plastic brick method. This would be particularly helpful to offset the inaccessibility of the bricks for vulnerable populations resulting from the price of prefabricating a unit. DARE would benefit from a more structured training program for the bottle masons to spread the practice and promote the houses. A structured bottle reclamation program with monetary incentives for DARE would also bridge the economic sustainability gap left by Conceptos Plasticos's supply chain program.

The intended potential of this research is to establish a set of rubric questions that determine if an architectural project is sustainable, in what and how many ways is it sustainable, and if it is a suitable practice for a person's needs. The comparison between reuse and recycling is to highlight the pros and cons of each waste management practice. Understanding the differences can educate those who wish to make a sustainable impact on the reality of their options. Overall it brings awareness to the severity of the waste crisis while providing some hopeful opportunities to make a positive difference in the pursuit of sustainable architecture.

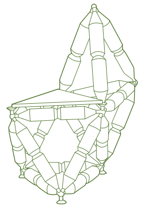
Booklet Setup + Approach

This booklet is a collection of 6 case studies that utilize reused plastic bottles significantly within their design. Prior to working with the case studies, much time was dedicated to research that justified the need for such a project. In-depth research on the environmental crisis, waste management trends, stewardship, sustainability, and ethics was conducted and recorded in the introduction to contextualize the need for an accessible how-to guide such as this one. Time was also given to establishing background information on bottles, reprocessing, and architecture to elaborate further on each piece of the content matter. It is curated as a 'how-to manual' so that others may learn how to incorporate these practices into their own lives. Some precedents for this method include The Underdome Guide to Energy Reform, by Janette Kim and Eric Carver as well as The Cannibal's Cookbook: Mining Myths of Cyclopean Constructions, by Brandon Clifford. The case study projects were selected based on their usage of plastic bottles in a minimally modified fashion, categorizing it as a reuse method rather than recycled. Initially, there was a much larger list of potential projects to document, but ultimately it was narrowed to the following 6 to emphasize different methods of incorporation while reducing redundancy. Such methods include different means of securing the bottle to the structures, using the bottle as a structural member itself rather than ornamentally, different types of bottles used, and various other materials used in addition across three scales of work. They are organized into three sections based on said scales with two small, two medium, and two large scale work examples. Each project in every scale section is divided into a Starter Kit, Instructions, and Post Production manual that recounts the preparation, parts, tools, modifications, creations, assembly, waste, and maintenance necessary for that method. The written information is accompanied by photos and diagrammatic graphics demonstrating the example structure, details, and steps. The conclusion of the booklet analyzes the case studies individually while making observations about their comparisons. It will evaluate what those trends could mean, and how plastic bottles in architecture can continue to develop.



Small Scale Works

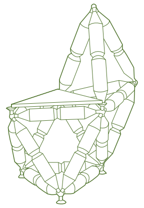
The small-scale works section examines projects that are predominantly smaller than the average human. This scale of work demonstrates how a person can occupy a design by being ON it. Specifically, this includes two furniture case studies where the project is experienced as an object within a space rather than a space itself. The furniture category of bottle architecture is particularly accessible to a wide group of people considering most of the population has or needs furniture. Material collection, availability, and cost are major factors in why the TrussFab and SIE43 chair processes are the most replicable projects for the public.



TrussFab

TrussFab is a plugin for SketchUp that allows the operator to fabricate structures that are sturdy enough to withstand their weight, plus that of a person.[28] TrussFab was created by Robert Kovacs and his team for the Human Computer Interaction Lab at the Hasso Plattner Institute in Potsdam, Germany. The plugin is an end-to-end system allowing users to fabricate sturdy, large-scale structures using plastic bottles and 3D-printed connections. It has the embodied engineering knowledge within the program to allow users to validate their designs using integrated structural analysis. It has the option to automatically convert existing models into a TrussFab structure or build one from scratch. Once designed, 3D files for all the connection hubs are converted and ready to send to the 3D printer. For façade designs, connector files are created and converted for a laser cutter. Each piece is labeled with a unique ID so the user can easily assemble the structure according to its digital counterpart. The plastic bottles are treated as beams within a triangular truss system.[29] Whereas a freestanding bottle tends to fail easily, the truss system prevents deformation of the structure, not the individual bottle.[30]

Photo by: Hasso Plattner Institute



Starter Kit

Preparation:

Download SketchUp, install the TrussFab plugin, collect plastic bottles (all of the same size, quantity depends on the design), adjust the bottle lengths in the software to match those collected

Parts:

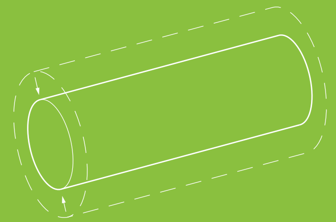
Plastic bottles, 3D printed connections (treaded connectors, snap-fit connectors, wood screw connectors), 3D filament, wood screws, dowel screws (optional), wide tape (optional), shrinking tube (optional)

Tools:

long screwdriver, drill, 3D printer, heat gun (optional), box cutter

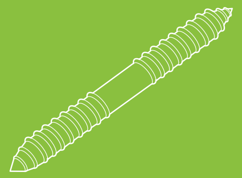
Parts:

Plastic Bottle

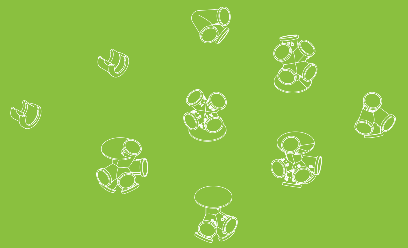


Shrink Tube

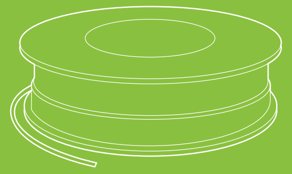
Wide Tape



Dowel Screw

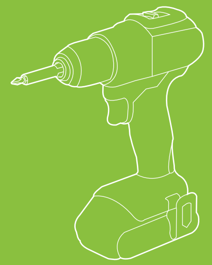


TrussFab Connections



Printing Filament

Tools:

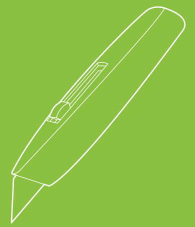


Drill

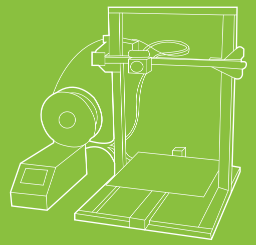
Heat Gun

Long Screwdriver

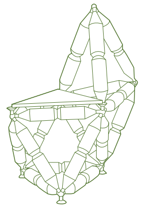
Computer



Box Cutter



3D Printer



Production

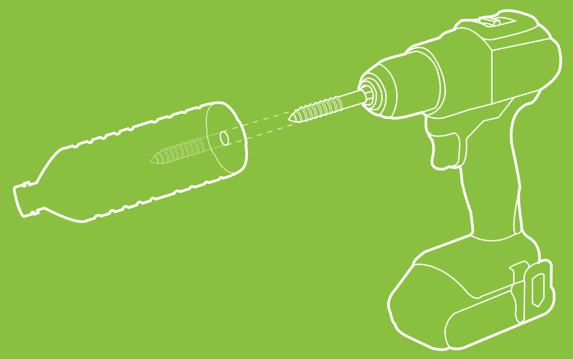
Modifications:

For option 1 – drill a hole in the bottom of the bottle just smaller than the selected screw. This could either be a wood screw or dowel screw. For option 2 – cut the shrinking tube so that it covers 2/3 of each bottle while they are placed bottom to bottom.

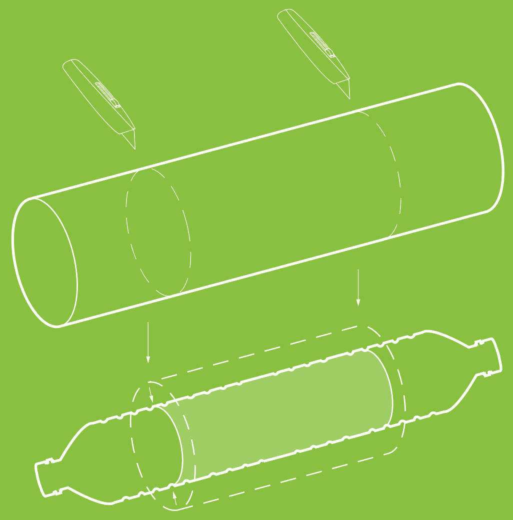
Creations:

Create a 3D model in SketchUp using the TrussFab plugin. 3D print all the necessary connections. For façade designs, do the same step but laser cut the connection out of wood.

Modifications:

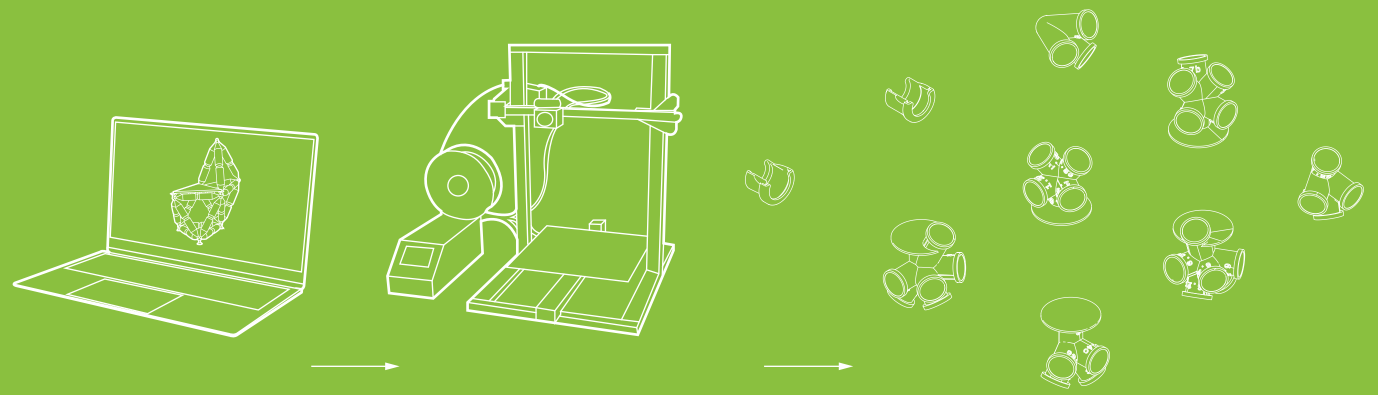


Option 1: Drill a hole in base of the bottles that will have a screw connection

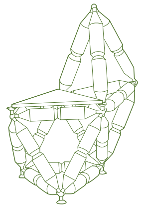


Option 2: Cut the shrink tube into the appropriate lengths relative to the bottles

Creations:



3D print all connections from the digital model



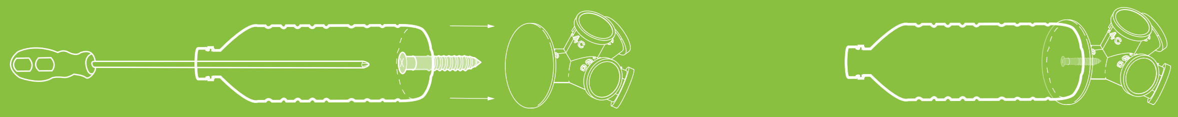
Production

Assembly:
There are multiple options for assembly that can be chosen based on the structure's design, material availability, and personal preference. By this point, the appropriate connectors have been printed for the design. For threaded connections, the bottle is screwed into the connector as if it were a cap. The snap-fit connector is used by inserting the connector into the mouth of the bottle. A locking pin is then inserted through the connector and into the bottle and expanding the piece for a tight fit. With the wood screw connection, a hole is drilled in the bottom of the bottle just smaller than the selected wood screw. The wood screw is then placed within the bottle where the tip is on the exterior where it will be screwed into the 3D printed connector with the flat platform. For optimal fastening, drill a pilot hole into the connector as well as the bottle. To create the truss beams, the bottles need to be bound together in one or two ways. An option is to drill a pilot hole into the bottom of two bottles. From here a dowel screw can be inserted into the bottle from the top and screwed into the second bottle using a very long screwdriver, or a dowel or double-ended screw can be manually screwed into both bottles from the bottoms. A second option is to cover two bottles that are arranged with the bottoms touching with a shrinking tube. The tubing should cover most of the bottles before applying heat to shrink it using a heat gun. Although fast, another less sturdy method of binding would be to use wide tape instead of shrink-tubing. Once all beams are created, the full trusses can be assembled using the connectors to complete the structure.

Assembly:

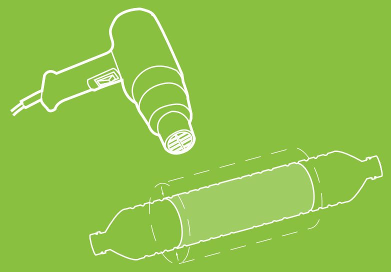
Threaded Connection

Snap Connection



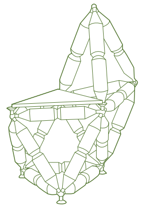
Screw Connection

Screw a bottle onto each end of the dowel scree to where the bottles are connected at the bases



Use a heat gun or hair dryer to shrink the tube around the bottles

Wrap wide tape around the two bottles



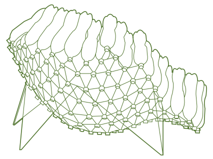
Post Production

Waste:

Potential waste includes the bottle caps, plastic shavings, and scraps of shrink tubing, 3D filament, or tape.

Maintenance:

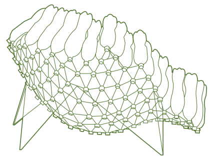
Depending on the wear and tear of the design, the 3D printed connectors may need to be replaced over time. If a bottle needs to be replaced, it can be unfastened from the connector and a new bottle can be fitted instead. This method would be suitable for outdoors, but long term should be kept indoors away from extreme conditions.



SIE43 Chair

The SIE43 Chair, by Pawel Grunert, was constructed for the 'Eco Trans Pop' exhibition at the Edizioni Galleria Colombari in Milan, Italy.[31] It is roughly 150 x 80 x 90 cm, composed of a stainless-steel frame, and populated by reused PET bottles.[32] The bottles are secured into the frame from the bottle tops. The bottoms-up arrangement is in an organic floral pattern representing the appearance of a flowing meadow while the caps form the base of the chaise lounge.[33] The eco art piece calls attention to the opportunities for material reuse. Although the framework of this chair is complex in form, the combination of a socket frame, used soda bottle, and cap fastener is a simple process to replicate.

Photo by: Pawel Grunert



Starter Kit

Preparation:

Collect and clean approximately 200 PET bottles (for a chair around 150 x 80 x 90 cm in scale). Verify that the cap and mouth of bottles are all the same size.

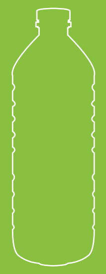
Parts:

PET bottles, Stainless steel rods (amount varies for desired design)

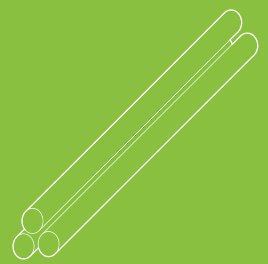
Tools:

Rubbing alcohol, Small towel (or equivalent), Scissors, Welder of choice, Angle grinder (or equivalent)

Parts:



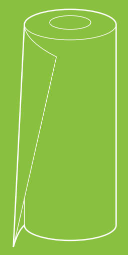
Plastic Bottles



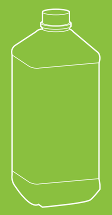
Steel Rods

Tools:

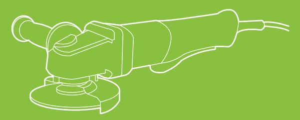
Scissors



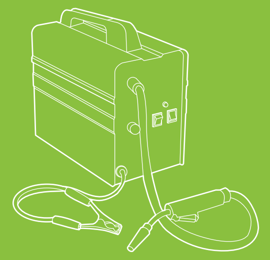
Towels



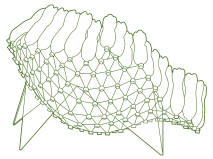
Rubbing Alcohol



Angle Grinder



Welder



Production

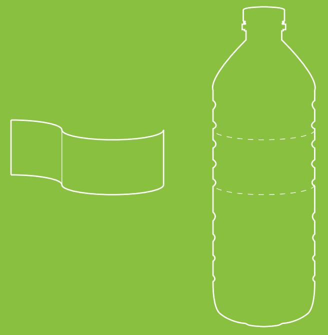
Modifications:

Remove labels and residue (step optional). Cut many stainless-steel rods into pieces a few inches long with the angle grinder (or equivalent) to become the socket spacers in the frame. Next, cut many stainless steel rods into pieces where the length is equivalent to the diameter of the bottle top, then work them into rings that will become the frame sockets. Cut remaining rods to the desired leg size for the chosen design.

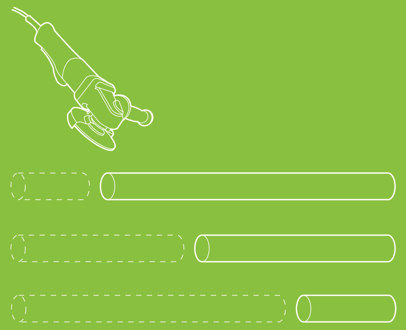
Creations:

Create a frame in the shape of the desired furniture by welding the stainless-steel rods into a triangular grid around the circular sockets which are large enough to house the mouth of the bottle. Shape the overall frame to the desired furniture design. Once the frame is assembled, weld the longer rod pieces to create the legs beneath it.

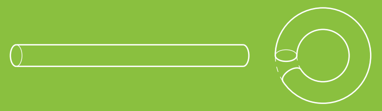
Modifications:



Remove labels

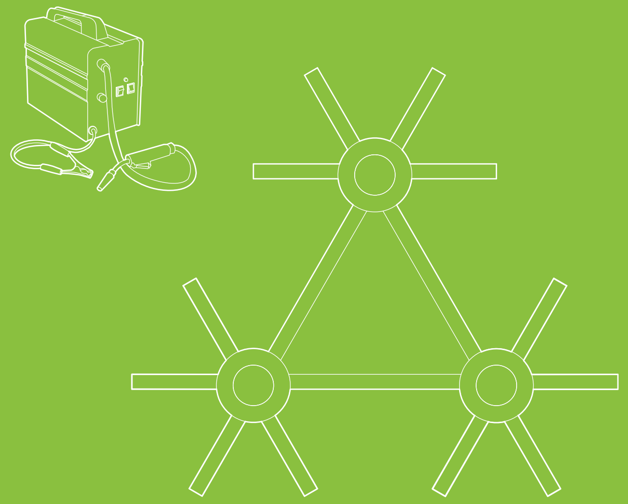


Cut rods into the required lengths

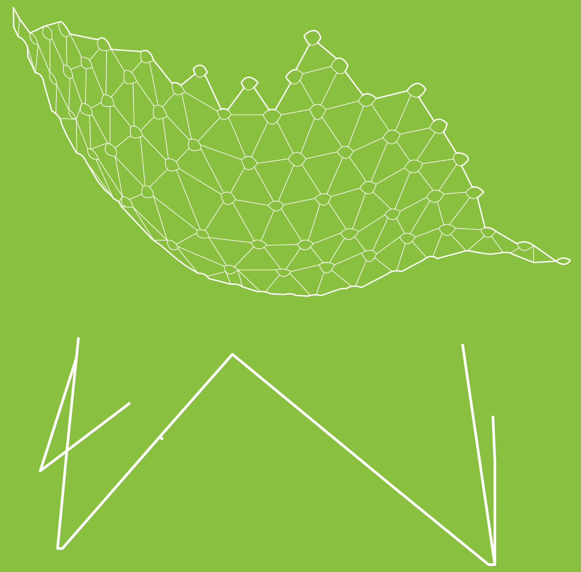


Bend rods into rings for the frame

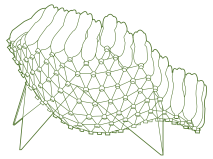
Creations:



Weld the rods and rings into a triangular grid



Shape the grid into the chair frame, then weld the legs into place



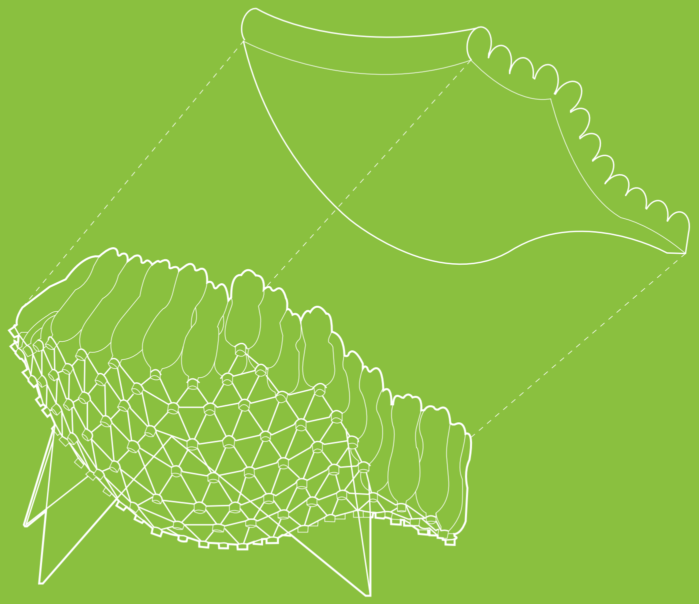
Production

Assembly:

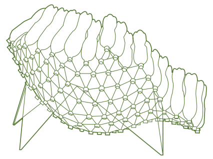
After the total frame is completed, screw the PET bottles into the frame sockets. The bottles should be organized 'bottoms-up' on the top side of the furniture frame and secured by the caps fastened to the underside. In the question of comfort and utility, pillows or padding can be added over the chair to increase the user experience.

Assembly:

Insert the bottles into the rings and screw the caps on to secure it in place



Apply padding to chair if desired



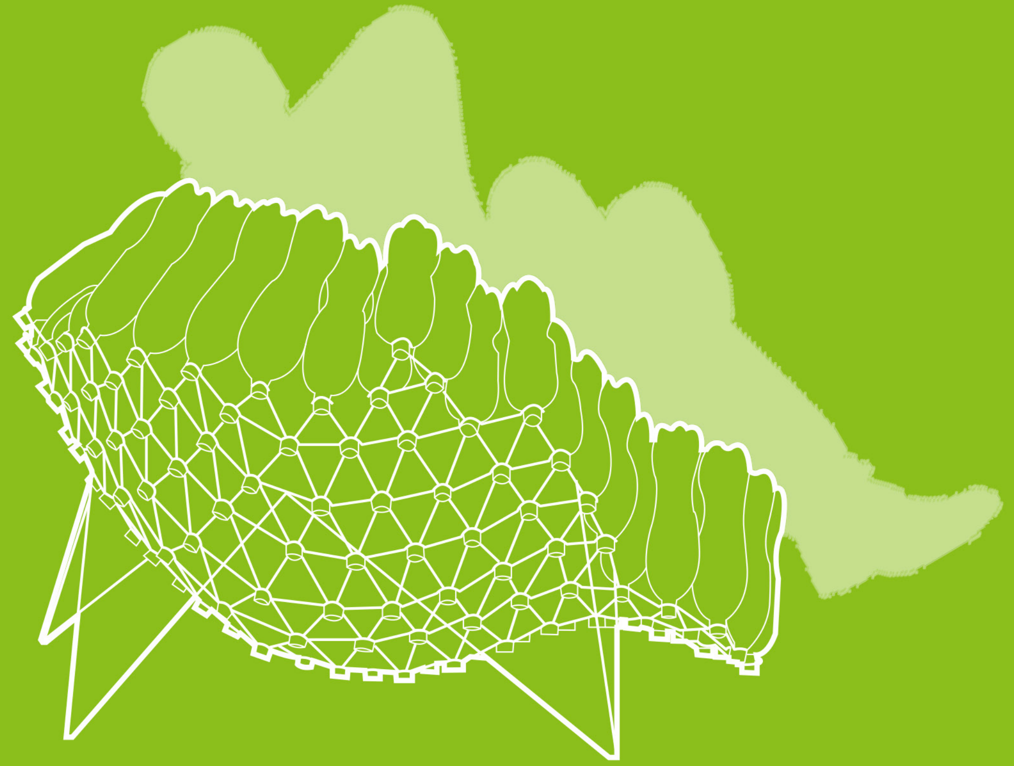
Post Production

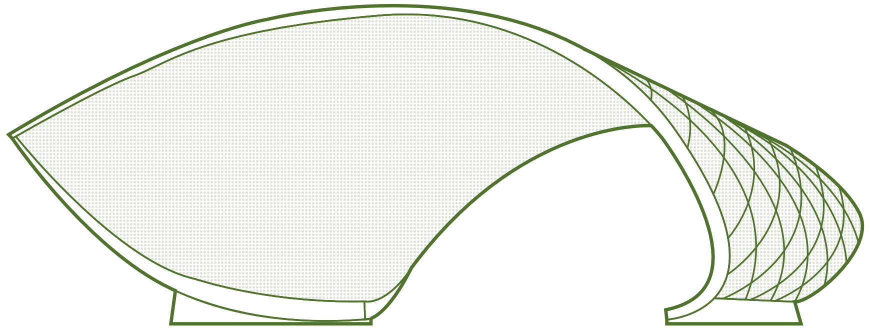
Waste:

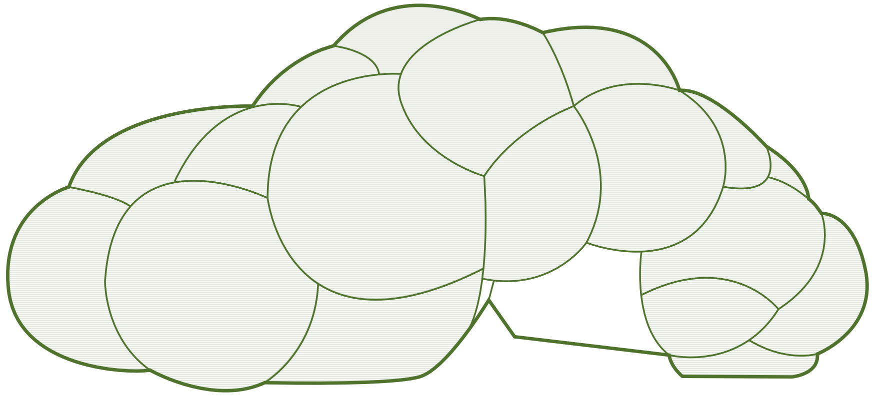
Potential waste includes metal scraps, shavings, and discarded bottle labels including the cleaning materials utilized.

Maintenance:

The design of this chair allows for easy bottle maintenance. When a bottle becomes damaged, it can be collected for recycling and replaced by a different bottle. The overall chair can become subject to melting in areas of high sun or heat exposure. The bottles my also lose their color in these conditions. Stainless steel does not rust easily, but it can in the right conditions over time. For peak lifespan, it is recommended that the chair remains indoors, but is functional in almost all environments.

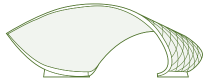






Medium Scale Works

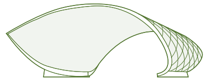
Medium scale work includes pavilions, think pieces, and sculptures. The work is now much larger than that of a person. The two pavilions represented in the following section demonstrate how a human occupancy occurs UNDER architecture and design. In scale, the medium case studies are the same as the large projects, but they differ in longevity and envelopment. The Cola-Bow and Head in the Clouds projects are both temporary exhibits used to raise awareness to the growing plastic waste crisis. They are open air structures that lack the full enclosure of the large-scale building case studies, but can be occupied by many individuals at once. Works such as this are very public making it easy to engage with, but there is less of a common need to replicate them.



Cola-Bow

Penda's Cola-Bow was designed and built-in 2013 for the 2nd Beijing University Creation Expo where it remained standing through Beijing Design Week. It is made from over 17,000 recycled plastic bottles forming a pavilion inspired by the shape of the swings on the Coca-Cola logo. A joint initiative by Beijing Universities and Coca-Cola collected the bottles by offering one free Coke for every 10 empty bottles returned.[34] The bottles are secured to a mesh panel fixed to a steel structure. It was created to reclaim plastic waste, bring awareness to the issue, and promote the brand itself.[35]

Photo by: Penda



Starter Kit

Preparation:

Collect plastic bottles, the quantity depends on the scale of the intended design. The bottles must still have caps and can remain with their labels on. In this design the bottles are consistent in size, but this can be altered.

Parts:

Plastic bottles, mesh (metal or plastic) with gaps large enough to insert the bottle mouth, metal rods, fasteners appropriate to structure material

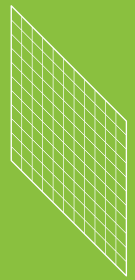
Tools:

Drill, miter saw, welder of choice, ladder

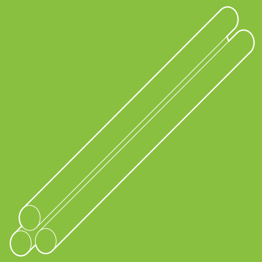
Parts:

Plastic Bottles

Fasteners

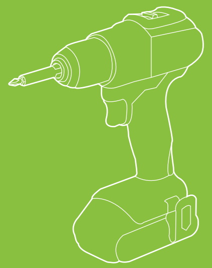


Plastic Mesh



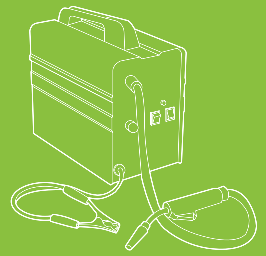
Steel Rods

Tools:



Drill

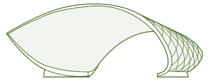
Miter Saw



Welder

Scissors

Ladder



Production

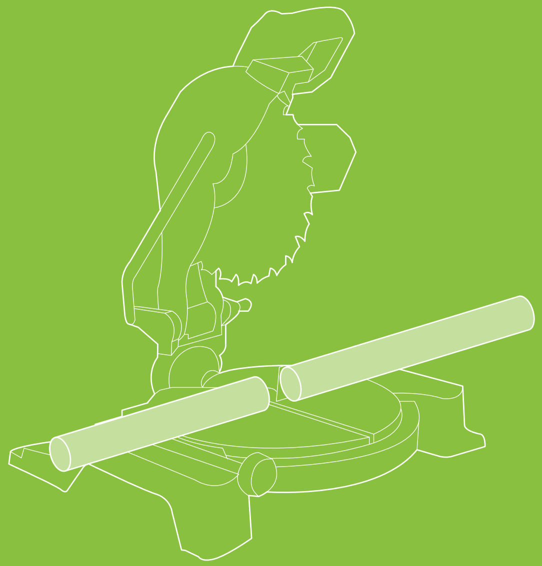
Modifications:

Cut the metal to scale with the miter saw, (the metal may be substituted with other building materials such as wood and secured with the appropriate fasteners). The size and quantity of the structure parts is determined by the design chosen. Cut the mesh into panels large enough to cover the underside of the structure.

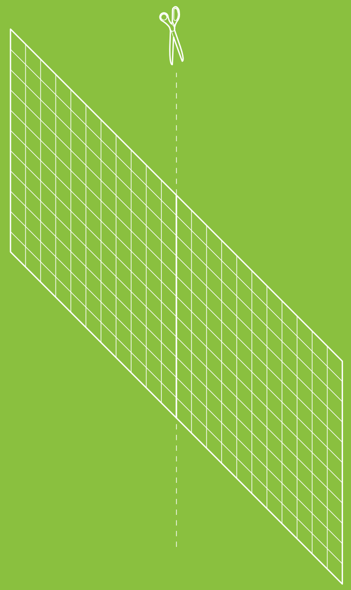
Creations:

Fasten the structure pieces with screws and a drill. If the primary structure is made of metal, the joints can be welded into place instead.

Modifications:

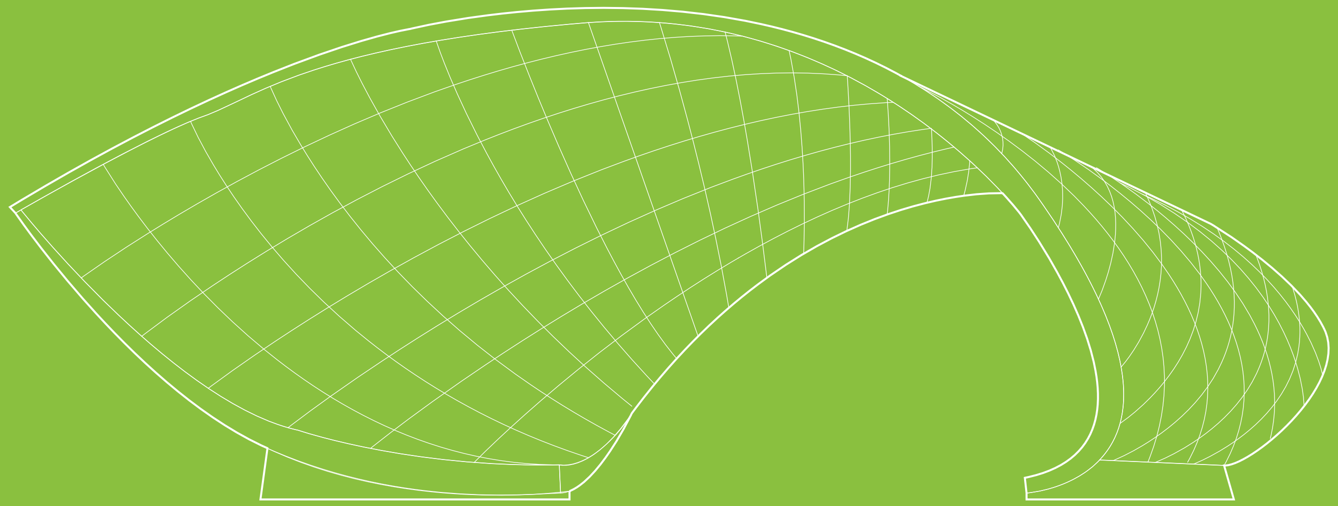


Cut rods to size

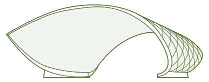


Cut mesh to size

Creations:



Assemble the structural frame

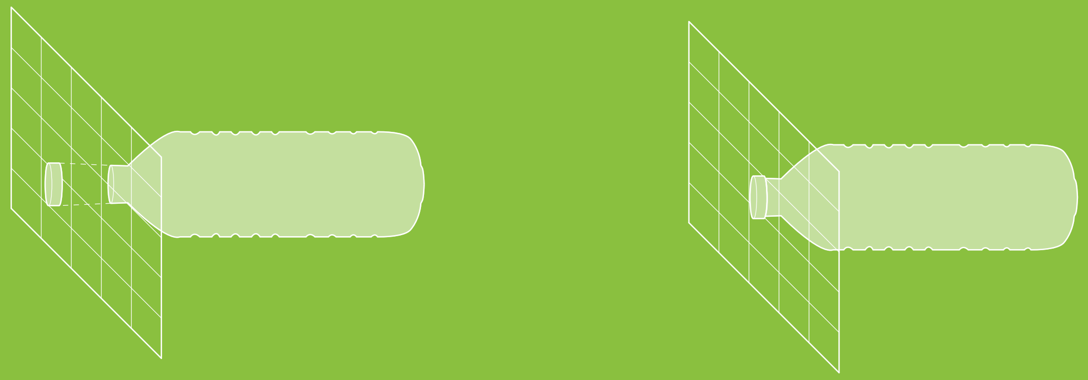


Production

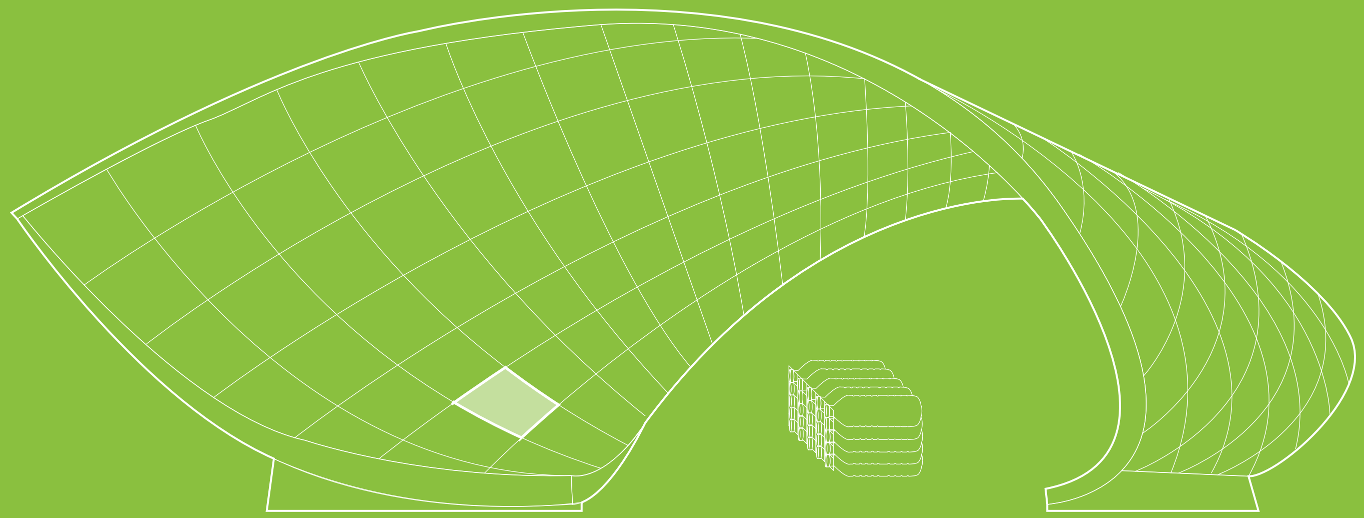
Assembly:

Once the structure is complete, insert the mouth of the bottle into the mesh gap. Screw the cap onto the bottle from the other side to secure it in place. When the mesh panel is full populated with bottles, lift into place and secure to the structure with the appropriate fasteners.

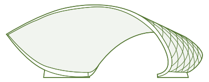
Assembly:



Insert the bottles into the mesh and screw the caps on to secure it in place



Secure the mesh panels with the bottles to the structural frame



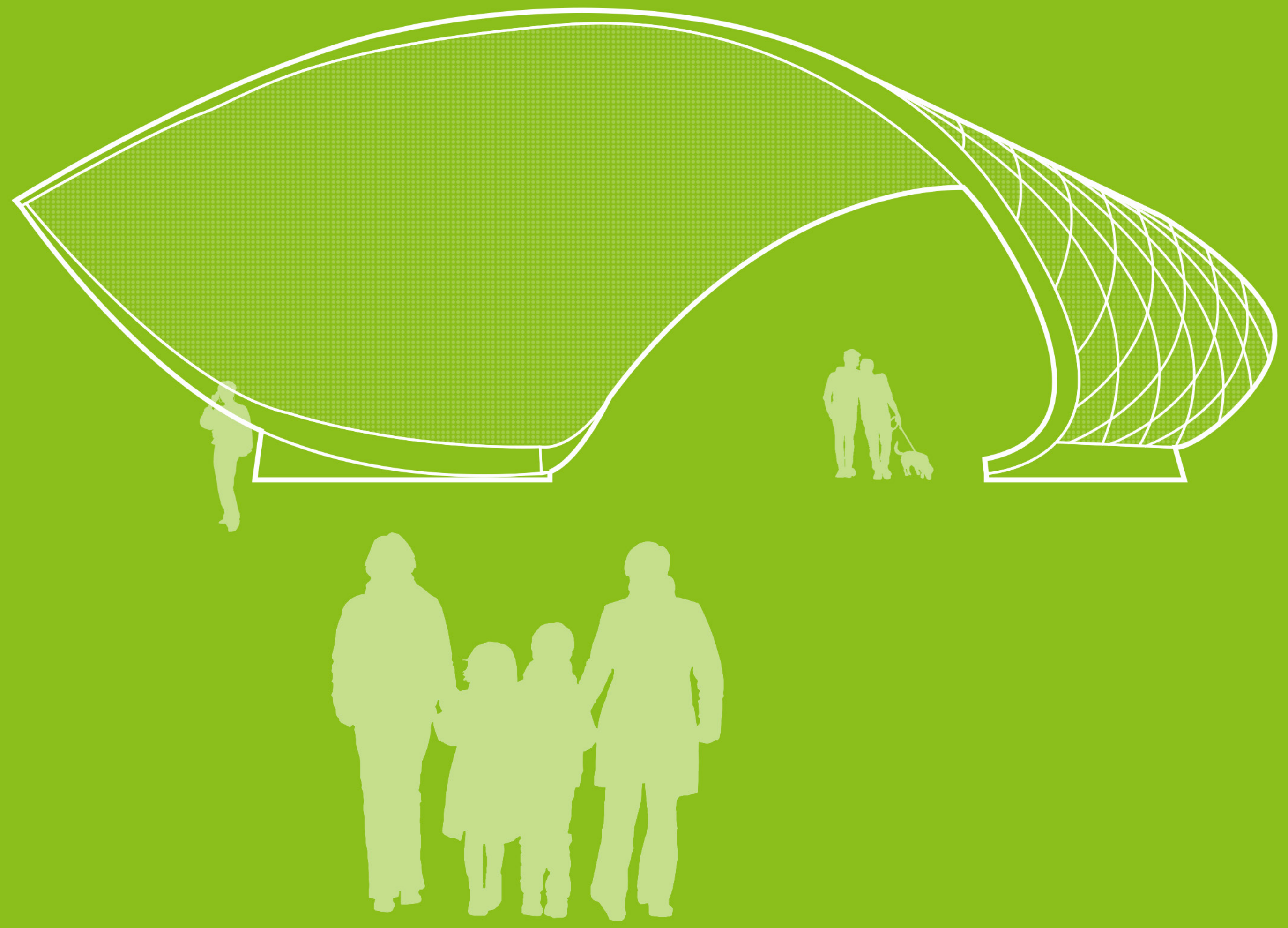
Post Production

Waste:

Potential waste includes scraps and shavings from the structure materials or mesh.

Maintenance:

Depending on the structure materiality, a sealant may be required to prevent weathering over time. If the mesh needs to be replaced, the panel can be removed, bottles collected, and replaced by new mesh. The previous bottles can be reinserted, and the panel can be reattached to the structure. Bottles may weather over time and lose color. If it is deemed necessary, then a bottle can be easily unscrewed and replaced.



Head in the Clouds

The Head in the Clouds pavilion was Studio Klimoski Chang Architects' response to the question "What would an art pavilion made out of recycled materials and based around the idea of 'The City of Dreams' look like to you?" posed by FIGMENT's 2013 art festival on Governor's Island in New York City. STUDIOKCA decided that an earthly cloud made of recycled water bottles was "A place to dream, in the 'city of dreams'." The pavilion is made of curved aluminum tubes supporting 120 'pillows' of one-gallon jugs and interior cladding of blue-dyed plastic bottles. There are 53,780 bottles used which is the number of plastic bottles thrown away in NYC every hour.[36] They were collected by local schools and organizations.[37] The structure is 40 feet long, 18 wide, and 15 high at its peak.[36] A wooden seating platform filled with sand acts as the base of the aluminum structure while the water in the dyed bottles adds additional weight and stability. Because of this, a foundation is not necessary.[38]

Photo by: Lesley Chang

Starter Kit

Preparation:

Collect 16oz and 24oz plastic bottles and white 1 gallon jugs that possess a cap, the quantity is determined by the size of the design.

Parts:

16oz and 24oz plastic bottles, white 1 gallon jugs, water, food dye, plastic mesh, aluminum tubes, zip ties, wood, sand, fastener of choice

Tools:

Miter saw, drill or hammer, welder of choice

Parts:

Tools:

Production

Modifications:

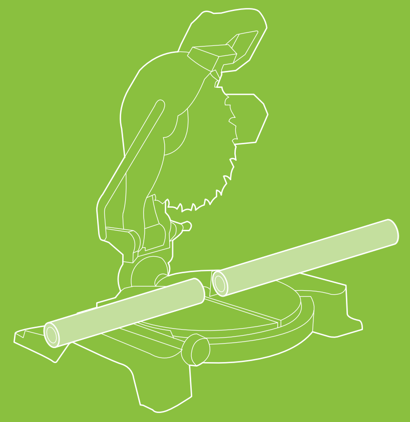
Partially fill the plastic bottles with water. It is optional to add food coloring to the water. Cut the aluminum tubes to size with a miter saw for the structural frame per design needs, (the aluminum may be substituted with other building materials such as wood and secured with the appropriate fasteners). Curve the tubes if desired.

Creations:

Assemble the aluminum tubes into the intended frame design. Build a base from wood that will secure the aluminum tubes. Fill with sand to ensure stability.

Modifications:

Partially fill the bottles with water and dye



Cut tubes to size

Curve the tubes for the frame if the design requires it

Creations:

Assemble the structural frame and wooden base filled with sand

Production

Assembly:

After the structural frame is completed and secured to the wooden base, begin assembling the jug 'pillows' and bottle panels. For both, insert the moth of the bottle or jug into the mesh and secure it on the other side by screwing the cap back on. The pillows will consist only of gallon jugs. The bottle panels can be a mix of 16oz and 24oz bottles. Once the panels are finished, secure the jug panels to the exterior of the aluminum frame with zip ties. Then, secure the bottle panels to the interior in the same manner. Depending on the design, a ladder may be required.

Assembly:

Insert the bottles into the mesh and screw the caps on to secure it in place

Secure the mesh panels with the bottles to the structural frame

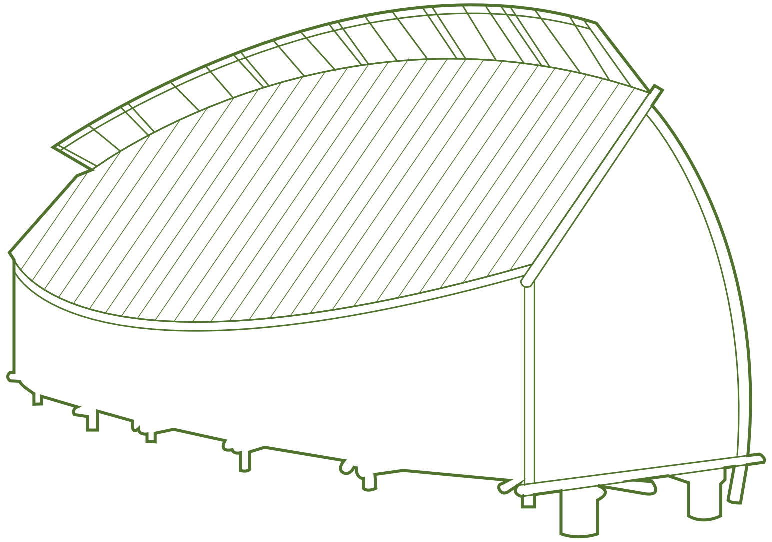
Post Production

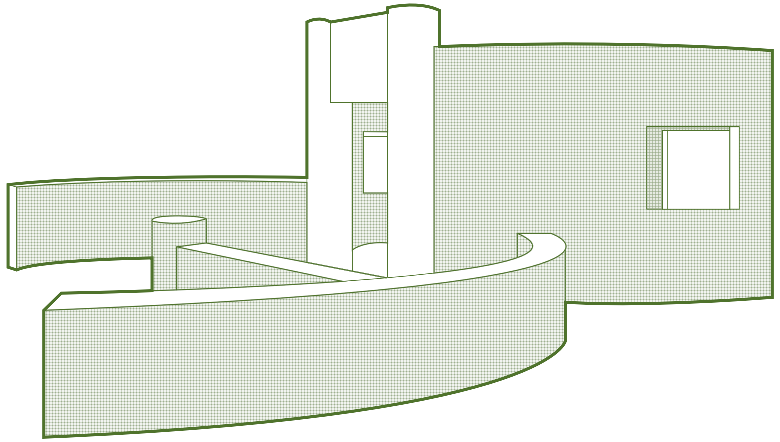
Waste:

Potential waste includes metal, wood, mesh, and zip ties scraps. It could also include waste from the food coloring packaging.

Maintenance:

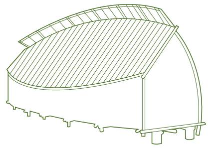
The wood platform should be finished with a protective sealant to prevent weathering. If necessary, a plastic bottle can be replaced by unscrewing it from the mesh and inserting a new bottle.





Large Scale Works

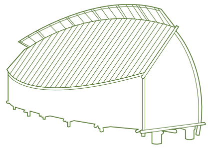
Large scale work is focused on permanent buildings that maintain a level of full enclosure. Occupancy and engagement now occur WITHIN the structure. The Bottle Sail and Bottle House are two examples of projects that use plastic bottles to address the waste crisis in addition to other social issues such as housing and community cohesion. Housing crises are global issues that could successfully be addressed in a sustainable fashion while simultaneously reducing plastic waste. Because the plastic bottles are readily available, the material costs for social projects are much lower than standard building practices. Plastic bottle architecture presents a viable solution for such issues and thus is a very accessible construction alternative.



Bottle Sail

1+1>2 International Architecture JSC collaborated with COHED in the Do Son district of Vietnam to create a structure for rural communities affected by HIV/AIDS aiming to improve the quality of agricultural and community connections to help people socially reintegrate. Hai Phong averages 12 typhoons each year, so the bottle seedling house was designed to withstand natural disasters and protect the plants. The foundation is a series of concrete piers embedded deep into the earth. Atop the foundation is a bamboo frame system that is approximately 1000sqft. It is roofed by 3000 plastic bottles which are strung together by bamboo rods. Each rod is run parallel to each other providing protection from rain, wind, and diffusing light on the interior. It serves roughly 10,000 tomato seedlings per season, as a place for farmers to relax, and as a location for after-school extracurriculars.[39]

Photo by: Vu Xuan Son



Starter Kit

Preparation:

Collect plastic bottles of the same size, the quantity is determined by the proposed design. The labels are optional, and the caps are unnecessary.

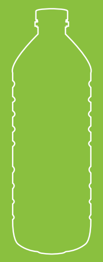
Parts:

Plastic bottles, bamboo (can be substituted for metal tubing), string, concrete

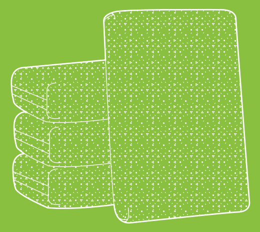
Tools:

Box cutter, saw of choice, shovel or excavator, cement mixer or drill with mixing attachment

Parts:



Plastic Bottle

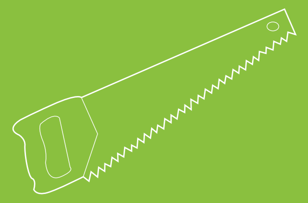


Concrete

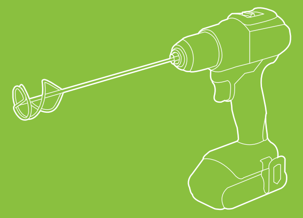
Bamboo

String

Tools:

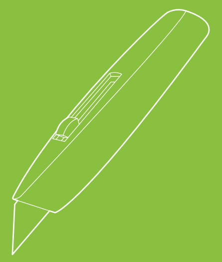


Hand Saw

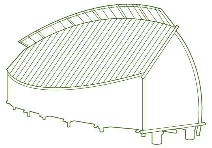


Cement Mixer

Shovel



Box Cutter



Production

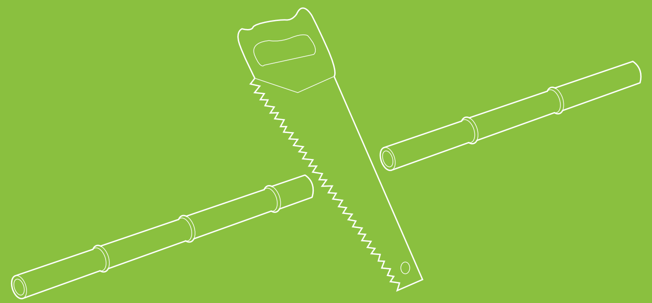
Modifications:

Cut the bamboo to size with a saw for the structural frame per design needs, (the bamboo may be substituted with other building materials such as metal and secured with the appropriate fasteners). Cut the bottom of the bottles off with a box cutter at the point where another bottle can then be inserted inside. This point will vary based on the design of the bottle.

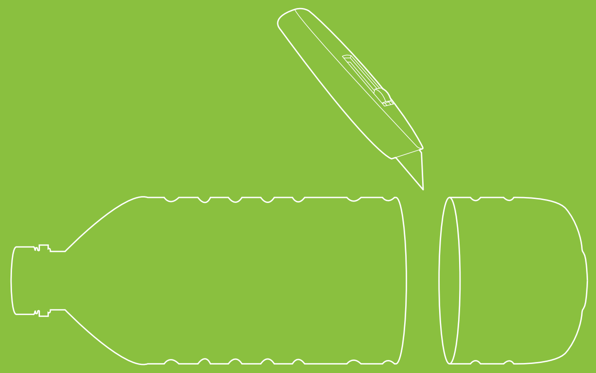
Creations:

Due to the light weigh nature of the bamboo frame, a foundation will most likely be needed. Excavate the earth and bury a concrete footing that extends 6 inches to a foot above the ground so the frame may be secure to it. The depth of the pier should be determined by the environment that the structure is located in.

Modifications:

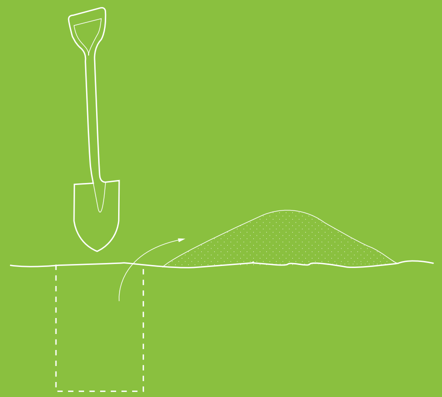


Cut bamboo to size

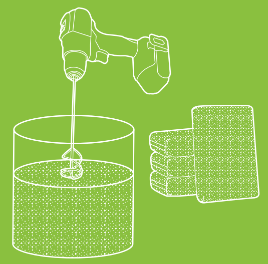


Cut the bottom of the bottles off

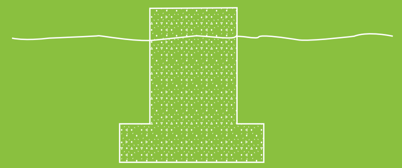
Creations:



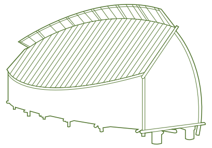
Excavate earth for the foundation



Mix the concrete for the foundation



Pour the concrete for the structural piers

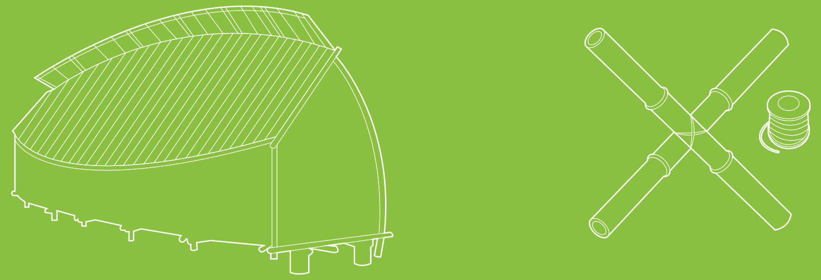


Production

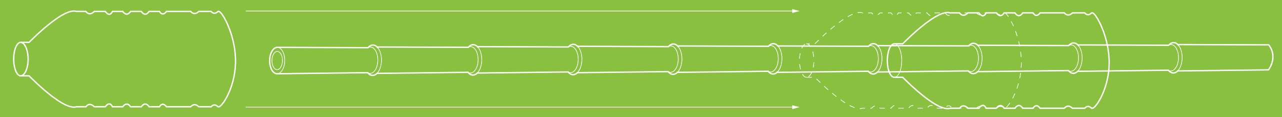
Assembly:

Build the bamboo floor and frame securely to the foundation or other source of stability. Bind the bamboo with string at the joints. Once the structure is complete, thread the modified plastic bottles onto a bamboo rod where each bottle is inserted into the previous one. When the rod is fully linked with bottles, attach each end to the structure. The rods can run parallel or perpendicular to the ground; this is determined by the desired design. Repeat the bottle rod production and attach directly beside the previous one until the roof is complete.

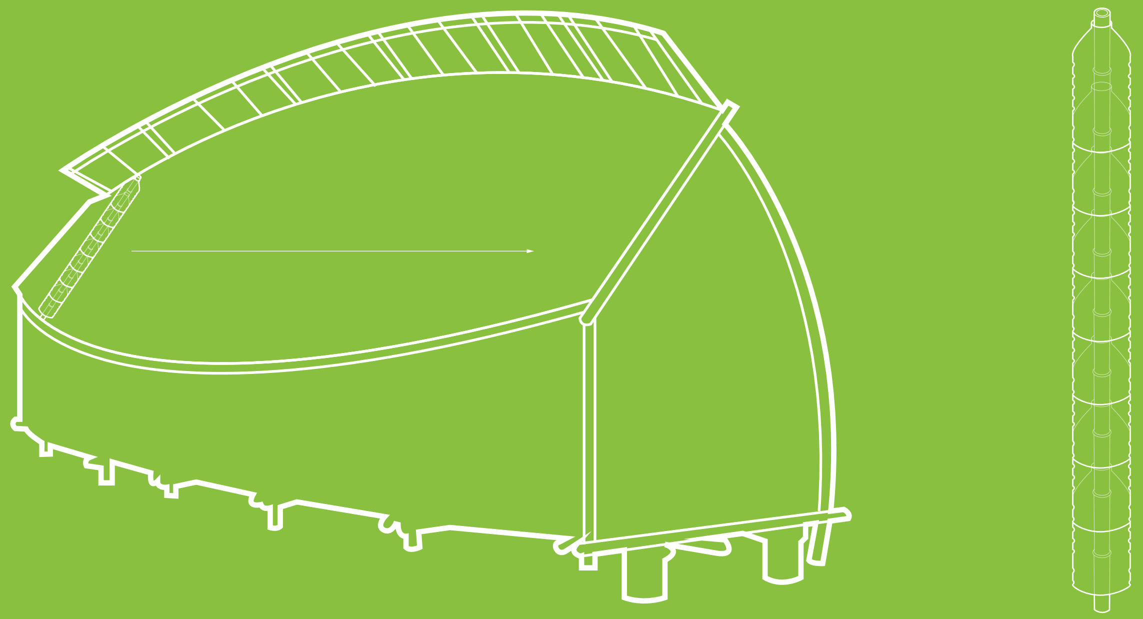
Assembly:



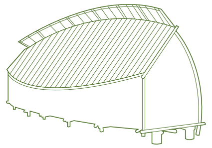
Build the bamboo structure and bind with string



Thread the modified bottles onto a bamboo pole



Attach the bottle rod to the structure parallel to each other



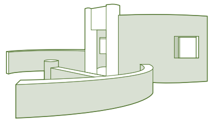
Post Production

Waste:

Potential waste includes the bottle caps, the bottoms of the bottles that are cut away, string and bamboo scraps.

Maintenance:

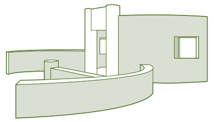
The structure will be subject to the elements, so the bamboo may need to be finished with a sealant to combat weathering. Damaged string at the joints can be rebound with new string. If a bottle link needs to be replaced, the rod can be unbound from the structure, the bad bottle can be removed, and the new bottle can take its place with the other viable links.



Bottle House

This plastic bottle house was built in 2011 in Kaduna, Nigeria. The initiative was founded by a Kaduna-based NGO, Development Association for Renewable Energies (DARE), with the help of a London-based NGO, Africa Community Trust to help tackle the housing and waste crisis.[21] Nearly 20,000 bottles were collected from the garbage, streets, or eateries and used for the full structure. The bottles are selected by size then packed with sand, bound by string, and cemented in place with clay and mortar. They are earthquake, bullet, fire, and weather resistant while being 18 times stronger than regularly available bricks.[8] Due to the thermal capacity of the bottle bricks, the interior of the structure maintains a temperature of around 64 degrees Fahrenheit year-round.[22] After three stories the structure can no longer continue as a result of the weight of the sand-filled bottles. This building practice is about 1/3 the price of similar buildings due to the cost of materials and has a round design to emulate an African appearance.[23]

Photo by: Andreas Froese



Starter Kit

Preparation:

Collect plastic bottles of a consistent size (approximately 100 bottles per square meter of structure). Labels can remain on. Caps are needed.

Parts:

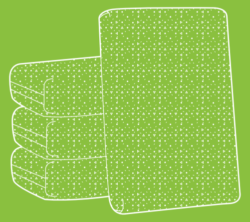
Plastic bottle, string, sand or soil, cement, water

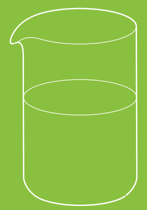
Tools:

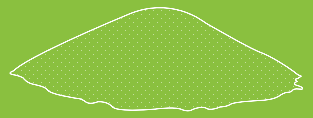
Dowel, sponge, level, trowel, shovel or excavator, scissors, cement mixer or drill with mixing attachment

Parts:


Plastic Bottles

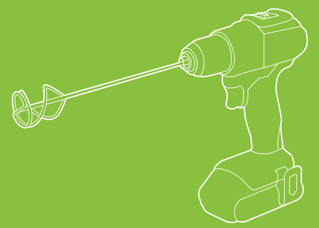

Cement


Water


Sand / Soil

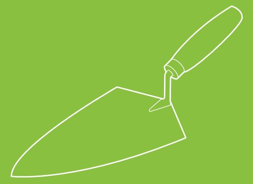

String

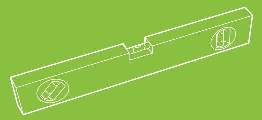
Tools:


Cement Mixer


Shovel

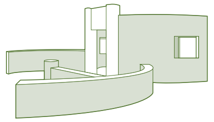

Scissors


Trowel


Level


Dowels


Sponge



Production

Modifications:

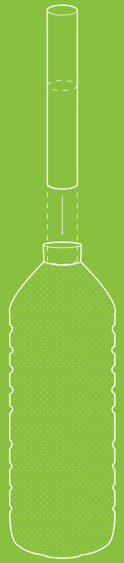
Fill the bottles with sand or soil and compact them using a stick or dowel. Replace the cap securely.

Creations:

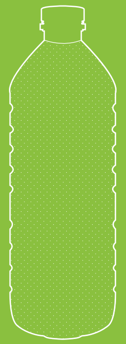
Depending on the size of the structure, a concrete foundation may be required. The excavated soil can then be used to fill bottle bricks.

Modifications:

Fill the bottles with sand

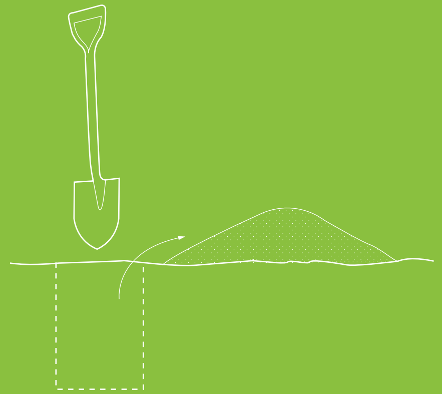


Compact the sand / soil

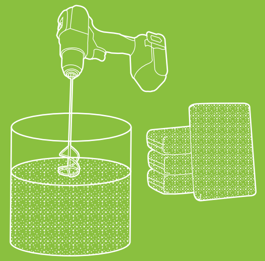


Replace the cap

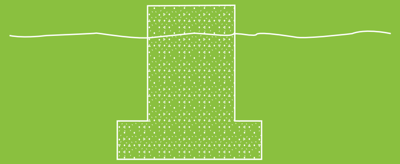
Creations:



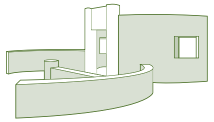
Excavate earth for the foundation



Mix the concrete for the foundation



Pour the foundation

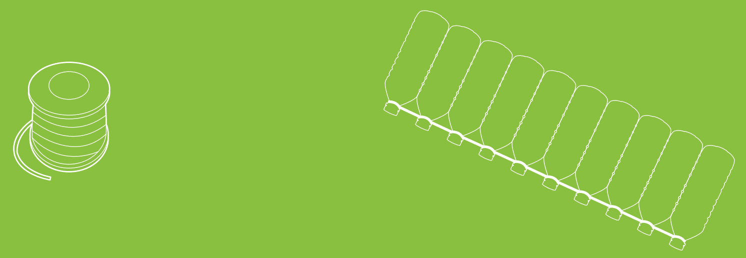


Production

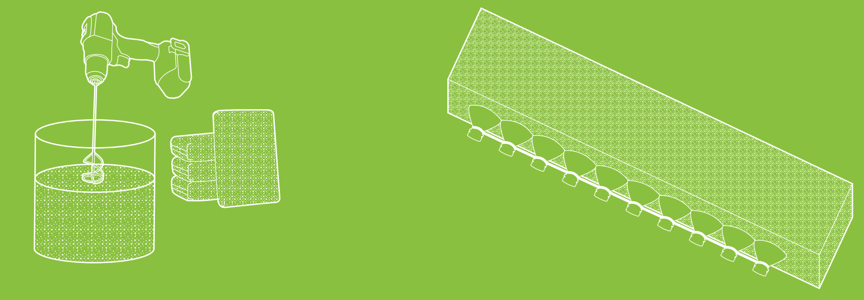
Assembly:

Arrange the first layer of filled bottles in the desired shape. Secure the string around the neck of the bottles and fill in the gaps with cement. Stager the next layer of bottles on top of the existing layer where the bottles are resting in the gaps of those below. Secure with string around the bottle necks and cover with mud. Repeat this step until desired height is reached. Check the structure periodically with a level. Lastly, take a wet sponge and smooth the mud surface.

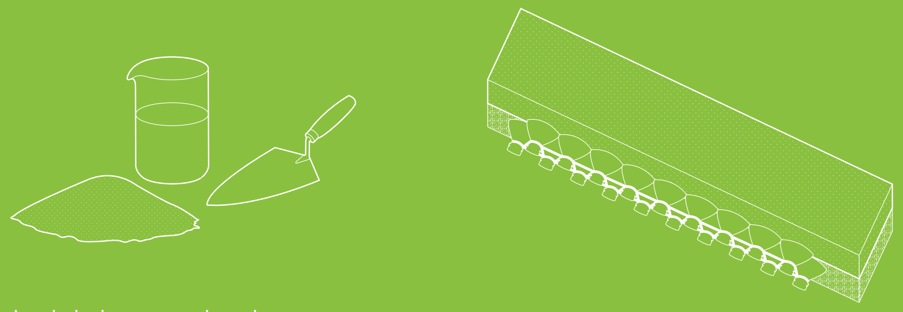
Assembly:



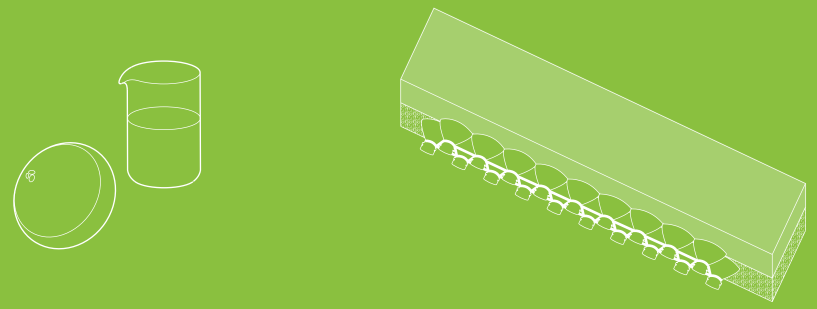
Arrange the filled bottles and bind with string around the neck



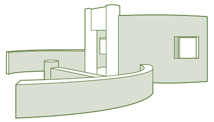
Surround the first layer in cement



Stager the next layer of bottles on top of the existing layer, bind with string, surround in mud



Smooth the mud layers with a wet sponge



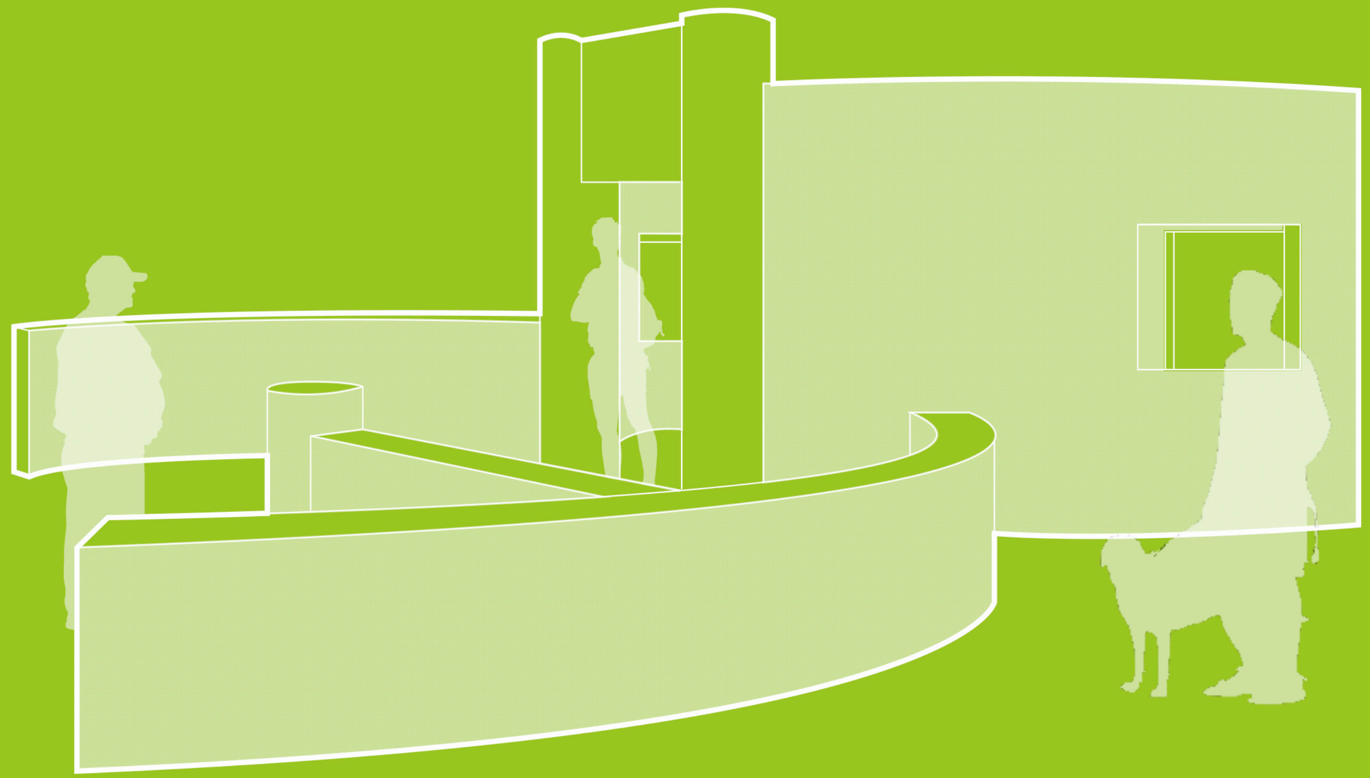
Post Production

Waste:

Potential waste includes scraps of string and dowels.

Maintenance:

The bottle bricks are incredibly strong, and most likely will not need to be replaced. The mud mortar will need to be maintained occasionally as it is subjected to wind and water. If the string that secures the bottles begins to fray, it can be reinforce or replace by new string.



Conclusion

Research intent

The intent of this research, as previously stated, was to investigate a few key questions surrounding plastic bottle reuse in architecture. The focus was on questioning how has plastic bottle reuse in architecture been done so far? Why have these case studies been done? The primary goal was to see how the practice of reusing plastic bottles in architecture can continue in an accessible way for anyone. This booklet is an attempt to convey those methods of construction simply and graphically to foster replication by anyone through the lens of a 'how to guide.'

Small scale observations

The small-scale work section examined projects that are smaller than the average person. The two furniture works demonstrated how one could occupy a design by being ON it. The bottles are used as structural beams or as 'flooring' (in terms of surfaces) because the loads applied to them are small. The experience was about an object in space rather than a space itself. The size of the pieces means that fewer materials and labor hands are required. Due to the DIY crafty nature of the work, it is the most replicable section of projects. That considered, the furniture projects do not typically serve any vulnerable populations making them the least socially sustainable cases. The intention is primarily about waste reduction in the environment with few economic or social drivers.

Medium Scale Observations

Medium-scale work included two pavilions. The scale has increased over that of humans turning the focus to occupancy UNDER architecture. In terms of size, the pavilions are similar to the large-scale works, but they differ in longevity and sense of envelopment. They are open-air and lack the full enclosure of the large-scale work. The case studies in this section are awareness based on the growing plastic waste crisis. Temporary work such as this is very public making it easy to engage with, but there is less of a common need to replicate them. The bottles are used as cladding for aesthetic appearance rather than structural necessity. Because of the purpose of awareness, the case studies are more socially sustainable than the small-scale projects. However, their temporary nature renders them the least economically sustainable. There would be more opportunities to benefit economically through furniture production due to the higher demand for such a project.

Large Scale Observations

Large-scale works focused on two permanent buildings with a maintained level of full enclosure. Occupancy and engagement now occur WITHIN the design. Both cases use plastic bottles to address the waste crisis in addition to other social and economic issues such as housing and community cohesion. Because plastic bottles are readily available, the material costs for social projects are much lower than standard building practices. The bottle as a unit has been reincorporated into the structure through the roof and the wall. The demand from, and service for, vulnerable populations means that plastic bottle architecture presents a viable solution for such issues and thus is a very accessible construction alternative. The large-scale works category has revealed itself to be the most sustainable in terms of the economy, society, and the environment.

Summary

Through analysis of the six case studies as a whole, some trends can be identified. The most common method to attach the plastic bottles is by securing the mouth to the structure either by custom joints or by sandwiching it between the bottle and the cap as seen in the TrussFab, SIE43, Cola-Bow, and Head in the Clouds projects. Only two projects, TrussFab (as a beam system) and Bottle House (as a masonry unit), use the bottle as a structural member. The Bottle Sail is the only example that doesn't use the bottle entirely, excluding the cap. It makes the most significant modification by cutting away the bottom portion of the bottle to become roof cladding. Bottle Sail, Cola-Bow, and Head in the Clouds all utilize plastic bottles for a roof/wall cladding system.

A clear benefit of all six of the case studies is the resulting plastic waste reduction within the environment. Although, the medium-scale projects are temporary, so one can only wonder what will become of the used materials once it is no longer needed. The small-scale furniture works are likely to outlast the pavilion but lack the longevity of the large-scale buildings. For this reason, the large-scale cases are the most successful and removing and keeping plastic waste out of the environment.

A downfall of the small-scale work is the lack of depth regarding social and economic sustainability. Although more economically feasible than the medium cases, they fail to serve awareness and vulnerable populations the way the two larger groups do. When considering all the purposes, methods, and effects of each project category, it is clear that the large-scale case studies, Bottle Sail and Bottle House, have the most multifaceted benefits regarding sustainability.

Future Implications

Potential implications for this research in the future are heavily focused on educating the public for awareness and action. The collection of research and case studies within the booklet will increase the public's general knowledge of plastic bottles in architecture in addition to providing the means to replicate the methods described. Moving forward, the goal would be to continue the compilation of information and case studies to grow this collection of knowledge. Ideally, the recognition of the plastic waste crisis and creativity in using these methods will inspire more progress for construction using reused plastic bottles.

Acknowledgments

I want to acknowledge several people who have helped me in my pursuit of design and say thank you.

Firstly, I would like to thank the University of Arkansas, the Honors College, and the Fay Jones School of Architecture and Design for challenging me to be the best student I could be over the last five years. Thank you for providing the environment on campus where I worked/lived as I dedicated my life to this degree in architecture.

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To my mother Twila, father Lance, and brother Nicky for being my best supporters. Thank you for your unwavering belief, pride, love, and humor for me. Because of you, I have never gone without.

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Lastly, I want to acknowledge my classmates from Fay Jones. For the last five years, I have had such a close community of peers to lean on and grow with. I never questioned that if need be, I had around 60 people I could count on. It saddens me knowing that this has come to an end, but I am excited to witness all the accomplishments we will have in the coming years. Specifically, I want to thank Isai Castaneda, Kayla Ho, Ryan Harris, Taylor Conover, Ramsey Yarbrough, and Ben Ebbesmeyer for becoming some of the best friends I have ever made.

Thank you all.

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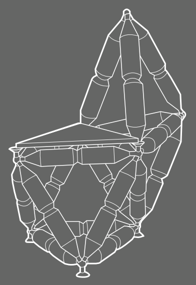

TrussFab (pages 16 - 25)
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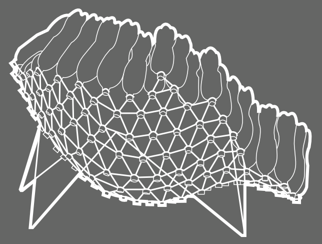
Robert Kovacs and team
28. (HCIHPI), "Connect PET Bottles, Make TRUSSFAB Structures."
29. Schires, "This Sketchup Plugin Designs Structures Made from Plastic Bottles and 3D-Printed Joints.
30. Kovacs, "Fabricating Sturdy Large-Scale Structures on Desktop 3D Printers."



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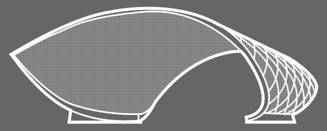
31. Yoneda, "Pawel Grunert's sie43 Chair Is Made from a Cascade of Clear Blue Plastic Bottles."
32. Tworze.com, Siedziska seats Meblarium Pawel Grunert.
33. Toby, "Pawel Grunert Still Finds Time to Design with a 'Re Purpose'."



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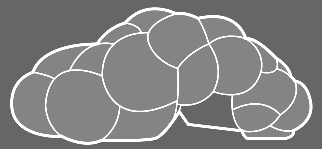
34. Furuto, "'The Cola-Bow' Installation / Penda."
35. Lisa, "Beijing's Cola-Bow Turns 17,000 Plastic Coke Bottles into a Curvaceous Shelter."



Head in the Clouds (pages 48 - 57)
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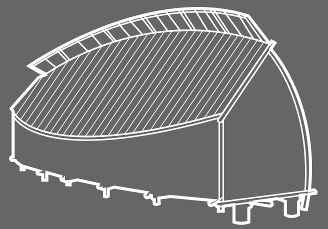
36. Rackard, "New York Firm Designs 'Cloud' of Recycled Plastic Bottles."
37. Klayko, "Figment 2013 Brings a Cloud of 50,000 Plastic Bottles to Governors Island."
38. Griffiths, "Head in the Clouds Pavilion by Studiokca Wins AIA Small Projects Prize."



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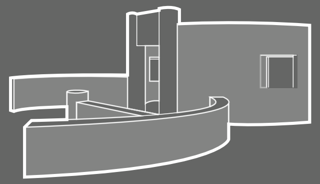

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