This case was prepared by the Design Robotics Group and authored by Anthony Kane under the supervision of Prof. Martin Bechthold for the purpose of class discussion. The Design Robotics Group is a research unit within the Harvard University Graduate School of Design. The author would like to thank Arthur Huang and Johann Boedecker for their assistance in developing this case. © 2011 Prof. Martin Bechthold.
1. Introduction

On November 6, Arthur Huang stood in front of the EcoARK pavilion, the centerpiece of the 2010 Taipei International Flora Expo. In addition to designing the pavilion, Huang’s firm Miniwiz Sustainable Energy Development Ltd had conceptualized, designed, tested, and manufactured, the unique plastic POLLI-Brick™ system comprising its façade. Made from recycled plastic bottles, polyethylene terephthalate (PET), the interlocking system of “bricks” was Miniwiz’s response to the challenge for low carbon sustainable building solutions. Merely an idea two and a half years prior, now 480,000 of the POLLI-Bricks, representing 1.5 million recycled PET bottles, looked down on Arthur and the 8.9 million visitors to the Taipei Expo. The road had not been easy.

2. Background

Taiwan has a population of 23 million and covers an area of 35,881 km², 2/3 of which are sparsely populated mountains. The remaining 1/3 is one of the most densely populated areas on earth and a major producer of trash. In the latter half of the 20th century Taiwan became a world leader in manufacturing; the largest producer of LCD panels in the world and the producer of 90% of the world’s laptop computers. Taiwan is especially known for plastics. According to Mayor of Taipei, Hau, Lung-Bin, “We were the plastic kingdom in the past…” Taipei is also the home of Far Eastern Group, one of the world’s largest producers of PET products. In recent years Taiwan has intensified recycling efforts; collecting 90,000 tons of PET bottles representing 90% of the 4.5 billion bottles consumed annually. The most common recycling process produces polyester fabric but not all PET collected is recycled. China is the final destination for large amounts of the world’s plastic, even coming from as far as the US and Europe. Because every kilogram of PET consumes 2 kg of oil in production, PET is often burnt for energy generation. The incineration process is deceptively called ‘energy’ or ‘heat’ recycling. As a further environmental hazard, Huang notes that large amounts of plastics, and their chemicals, accumulate over time in fish populations. As an island Taiwan consumes large amounts of fish and Huang points out the unpleasant irony of eating their own trash.

3. Miniwiz

According to Executive Assistant Johann Boedecker, Miniwiz is “A product design company that got into architecture” but he notes that developing building components was always a goal. Since its founding in 2005, Miniwiz has been a fusion of architecture and product design reflecting its founder Arthur Huang who has longtime roots in the manufacturing sector of Taiwan but holds degrees in architecture from Cornell and Harvard University’s Graduate School of Design. Nevertheless, developing building products required large amounts of capital for research and development; too much for the two person startup firm. Instead they took on architectural and product design commissions and had early success in consumer electronics.

The Hymini, one of Miniwiz’s most successful product lines, is a package of handheld universal chargers and adapters for “digital gadgets”. Products include a handheld micro-wind generator that can attach to bicycles, or a person’s arm, and a notebook size portable solar panel with adapters for cell phones, iPods, cameras, and other personal electronics. What started as a simple idea, portable solar and wind power, has resulted in a dozen different products including, a solar panel and wind generator, a series of chargers, adapters, bicycle connectors, arm band holders, and even personalized color options for the plastic casing. One can purchase the ‘basic’ or the ‘deluxe’ package as well, and up to four of the solar panels can be linked together. All the accessories and personalization options for the hymini product line serve to widen the potential market and turn what may have been a one-time purchase into a series of purchases.
4. Establishing a Business Case

Huang compares the process for product development to an academic thesis. First, you have to come up with a hypothesis. This precedes any design or form concepts and, at Miniwiz, is a simple three step process:

1. Identify a problem to solve
2. Identify a need
3. Identify a market application

For the POLLI-Brick in 2007, identifying the problem was as simple as looking in the office trash. Says Huang, “We literally looked into our trash can, that’s how we started. Our engineering team loves drinking bottled tea. It is such a culture in Taiwan.” The bottles of tea, like many beverage containers, were made from PET plastic.

The second step, identifying a need, came from Huang’s studies in architecture. In Taiwan, as in much of the world, buildings are made primarily of steel, concrete, and glass. Says Huang, “As an architect, I knew from the very beginning that our building material selection is all high carbon. We needed to come up with something different.” Including construction and operations, estimates are that the building sector consumes 40% of world energy; the source of 25% of world carbon emissions. However, Huang notes current efforts in sustainability focus primarily on building performance without including the embodied carbon in construction. In order to achieve true sustainability architects needed a new way of building lightweight, high-performing structures with low carbon footprints.

The market application would be the large number of warehouses and big box stores in Taiwan. These buildings are typically steel structures, with little to no natural light, and woefully inadequate insulation. They also have a short 10-15 year lifespan, and while some of the steel is recycled as scrap many galvanized elements are considered too difficult to recycle and end up in landfills instead. After identifying the box stores as a potential building type Miniwiz followed with a detailed market analysis calculating their square footage, where they are growing, and how much they cost. Miniwiz specifically targeted the metal-foam composite insulation panels commonly used as cladding as a product class where they could make the most impact. For Arthur sustainability is not about altruistic feelings or guilt about the environment. Truly sustainable products have to have a business model that meets a market need while being better performing and less expensive. This reflects the commonly accepted ‘three pillars of sustainability’; environmental, economic, and social sustainability. The big box building type provided an ideal market for a new sustainable building material.

The goal was to use Taiwan’s trash plastic as a lightweight low-carbon cladding system to replace metal-foam insulation panels in large warehouse and big box store applications. The development of the POLLI-Brick was underway.
5. Conceptual Design

According to Huang the initial phase, identifying the problem, need, and market application was quick, lasting only two months. But before the team started to look into designs they decided to research PET production methods.

While the form of POLLI-Bricks resemble their former life as plastic bottles this was not a foregone conclusion. The PET recycling process involves grinding the bottles into ‘flake’, separating out contaminants, and then heating and reforming. Any PET forming technology was possible. Miniwiz conducted research into extrusion, injection molding, blow molding, and different combinations of the three. They spoke with mechanical suppliers about different techniques and looked into production methods for the food, industrial, and building component sectors. According to Huang, “In the end we wanted some very simple data; which one is the cheapest? Of course it definitely was not building codes. "  

Huang, “In the end we wanted some very simple data; which one is the cheapest? Of course it definitely was not building product manufacturing because they are not efficient”. Instead, Miniwiz found inspiration in the efficiency and low cost of the food packaging industry that manufactures on the scale of trillions. This process of blow molding seemed an ideal production process for POLLI-Bricks.

Scalability is an important concern in product manufacturing. While architects design each project anew product designers must incorporate the anticipated scale of production. For example, a custom component may be justified at the scale of several thousand but quickly becomes unfeasible when producing 100 million products. Alternatively blow molding, once the mold and process are established, can make as many or as few of a product as demand dictates; resulting in a high scalability.

Once a material and a production method were chosen other decisions seemed to fall in place. The team found size limitations in blow molding PET. They determined that a panel of blow molded components would have to be comprised of many smaller interlocking units. In order to further the product sustainability they resolved to do this mechanically with as little chemical adhesive as possible. This also reflected Huang's interest in structural and mechanical systems such as traditional Chinese architecture made without glue or nails.

The material also informed the process. PET is naturally soft and most beverage bottles use as little material as possible to save cost. When a material is soft it must derive strength from its form. Miniwiz began to sketch out interlocking panels that could efficiently transfer weight. Using such a light material for a panel design Huang knew that lateral loading, rather than gravity loads, would be the critical determining factor and the team saved time and resources by considering lateral loading from the beginning.

These critical early decisions laid the groundwork for the more intensive design period to follow. Huang is quick to recognize that the design process is not as linear as sometimes presented, relating it more to a circle where each new decision feeds back onto earlier decisions, “but at certain junctures you have to decide on one solution. Otherwise, you cannot go on.”

6. Putting the Project on Hold

As someone with a background in both architecture and product design Arthur Huang is quick to point out that, unlike architects, product designers don't get paid for their design work but must recuperate their expense in product sales. After three months of brainstorming in early 2007 Miniwiz decided to put full scale development of the POLLI-Brick on hold. Without a source of funding the project was too great a risk. According to Huang the company also lacked the time, “We had other things to do to keep the company alive”.

In January 2009 Miniwiz presented a small scale interior version of the POLLI-Bricks at CES 2009, a consumer electronics tradeshow, along with their SolarBulb. The interior dividers were designed to incorporate the solar powered LED light as a plug-in. The product was well received but many doubted the small scale interior product could be converted into a large scale self-supporting façade panel.

Compared to the Miniwiz's previous consumer electronics products developing new building materials required long and expensive research and development to meet building codes. Huang half-jokingly points out, “The only testing required for computers is a self-declared CE [European Conformity] which means you don't blow up!” As an additional challenge, the PolliBrick proposed adapting production lines typically used for disposable food products to produce building grade materials. Finally, there was concern whether recycled PET, whose mechanical properties are not as consistent as virgin PET, could be used structurally. Could the engineering team design a system of interlocking PET forms strong enough to withstand Taiwan's typhoon winds? Could the production lines produce these units of sufficient size and thickness? Would the system pass building codes? Most important, would anyone buy them? Huang knew the concept was strong, but for a young firm the uncertainty was too great to invest heavily in research and development without a demonstration project and funding to achieve it. Luckily, the solution came in the form of the Far Eastern Group and the 2010 Taipei International Flora Expo.

The Far Eastern Group is a vast conglomerate of over 180 affiliated companies that span ten major industries. In addition to the aforementioned petrochemicals, Far Eastern Group is known for its construction and general contracting companies. In 2009 they approached Miniwiz to design a pavilion for the 2010 Taipei International Flora Expo. According to Arthur Huang, “They weren't expecting anything innovative from us.” However, as Miniwiz presented alternatives for Far Eastern Group's consideration Huang seized the opportunity to include the, as yet, preliminary POLLI-Brick concept. The risk was great. Huang recalls, “This was our daring endeavor. We promised the technology was there already. In our mind it was there… but it could have been a disaster.” Far Eastern Group was interested but unconvinced. As one of the largest producer of PET in the world Group Chairman Douglas Hsu, liked the idea of recycling the company's waste products. Their challenge to Huang; produce a prototype in two months!
7. Prototyping

POLLI-Brick development was back on track but the team was now under pressure. Despite the proposal, POLLI-Brick still lacked a clear design. They had presented a concept with no real structural feasibility. By the two month deadline they were able to produce a 1/50th scale prototype as promised accompanied by basic computer simulations of the structural performance; “It was very crude,” says Huang, “it wasn’t even the same shape as the final product.” Yet, even for this basic step Miniwiz had spent approximately $50,000 without a commitment or contract from Far Eastern Group.

Ultimately Far Eastern Group was pleased with the proposal and signed a general agreement. Huang now felt confident enough to promise a half scale working prototype in another two months. Arthur determined to eliminate any remaining doubts, “Once you see a real wall you can stand on it.” More engineering was necessary to solve the lateral loading and mechanical connections, bringing the design close to its final form.

While the early interior prototypes of the small POLLI-Bricks interlocked, the accumulated error of the product over an area the size of a building façade would lead to joining failures. The team used a laser cut polycarbonate sheet to create the panels, aid in the lateral loading, and eliminate imprecision in brick location. To demonstrate the final assembly could resist the lateral and gravity loads Miniwiz produced a two meter long bridge of POLLI-Bricks. To show how LED lights could be incorporated into the wall panels Miniwiz resorted to Christmas lights as a proof of concept. Finally they burned the prototype to prove it was flame retardant. At this point Miniwiz had spent, in total, nearly $200,000 in developing the POLLI-Brick. Huang recalls, “We take a lot of risks; that’s how we grow. This was a huge risk!” Far Eastern Group was convinced. In September 2009 they agreed to a full contract for the EcoArk and Miniwiz entered full scale research and development for production.
Huang is careful to explain that the contract was for the EcoArk project not POLLI-Brick research and development, “Clients don’t care about research and development. We just promised them a product. They aren’t going to pay for your research and development costs”. However, Miniwiz was in the unique position of being both architect and product designer on a project that would feature the POLLI-Bricks. The building form was fairly simple, partly due to its function as a pavilion, and Huang notes, “It literally took us five days to finish the building design... The rest was trying to make it work. It was supposed to be a stage for our new material”.

The EcoArk was steel construction with an envelope of POLLI-Brick panels. The structure was designed to be disassembled and reassembled in a new location after the Expo. The entire exterior surface was comprised of POLLI-Brick panels. The roof featured a large photovoltaic array to power the lighting, interior fans, and a water feature. The pavilion had no heating or air-conditioning instead relying on natural ventilation. To cool the space a section of the façade was left open to capture breezes and the water feature cooled the air as it passed into the building. Energy needs were kept low due to the large amount of natural light received through the POLLI-Brick. Product testing proved an insulation value of R-12 on the assembly.

In order to simplify the panel production process the building was designed to use only one size panel. The curved elements of the building were given a large radius to ensure there were no difficulties connecting the flat panels. Still there was uncertainty whether Miniwiz could meet the project deadline. With the Expo set to open in November Miniwiz had little over a year to solve the remaining design challenges, mass produce the panels and install them on the pavilion. Any number of technical challenges could bring the entire project to a halt but Huang had no backup plan. The fate of the company rested on success.

The process began with three months of production testing. While computer models were able to simulate the structural performance of the POLLI-Brick’s working out the production challenges would require grueling trial and error. Miniwiz collaborated with Huei-Jhan Yu a production supervisor with years of blow molding experience. The team began by testing mixtures of recycled and virgin material beginning with 10% recycled PET. At 30% recycled PET the production equipment began having difficulties due to the inconsistency of the material. Through a combination of sourcing cleaner, more homogenous, recycled PET and iterative adjustments to the production line Miniwiz was able to overcome these problems, eventually reaching 100% recycled PET content.

The amount of material was also a concern. According to Yu, “We found that the 130 gram bottle has insufficient side compressive strength. Therefore we increased the thickness of the bottle.”

The blow molding process begins with pre-forms, made by injection molding. The pre-forms are heated to a plastic state, and then blown with compressed air to fill the mold. Changing the wall thickness of the plastic required an iterative process to determine the precise temperature and air pressure needed to produce the POLLI-Bricks. Imprecision in the manufacturing process would prevent the POLLI-Bricks from interlocking.

Construction of the EcoArk pavilion had begun in November 2009. By February 2010 Miniwiz began mass producing POLLI-Brick, assembling the panels, and installing them onsite. In April 2010, less than five months after construction and seven months before the Expo opening, the EcoArk was complete.
10. The EcoArk and Pollibricks

In November the 2010 International Taipei Flora Expo opened with a theme of environmental awareness. The sustainably minded EcoArk with its POLLI-Brick façade was an instant hit. At nine stories tall and covering the area of six basketball courts it was a major demonstration and market opportunity for Miniwiz’s newest product. Its iPhone controlled lighting system, comprised of 40,000 LEDs, dazzled audiences while the pavilion itself educated them on the potential for recycling Taiwan’s trash into buildings. Huang is most proud that, at 9.2 million dollars, the building cost 1/10 of a neighboring pavilion and estimates the POLLI-Brick assembly costs 1/4 of conventional systems. This proved that POLLI-Brick could be a competitive product in the marketplace and validated Huang’s theory that sustainability should be profitable. Miniwiz had achieved their goal of developing a high performing, well designed, inexpensive, low-carbon alternative to large building.

The POLLI-Brick was so successful that the company no longer invests in traditional marketing. The product has generated numerous articles in papers, magazines, online news, and television spots on its own. The EcoArk was even featured in an hour long episode of National Geographic’s Megastructures. While Miniwiz was initially limited by their lack of funds to engage in speculative research their major concern now is controlling growth which Boedecker points out can be just as problematic. What started as a two person startup firm in 2005 had grown to 40 employees in house with another 20 external engineers by 2011.

Boedecker attributes the project success to the business model. He notes that utility is always the first step for Miniwiz. The EcoArk in particular had a very tight budget. For Boedecker the adage “Form Follows Function” is rephrased as “Form Follows Budget”. Whenever possible Miniwiz used existing technology and when scoping projects the teams asked, “What can we execute fast and cheap and that we know is feasible”. While all Miniwiz products challenge conventions it is difficult to develop a product that completely breaks with traditional methods. Boedecker stresses the importance of setting strong limitations in the beginning as guides.
11. Future Steps

The next steps distinguish Miniwiz from typical architects. As a product designer they do not see the EcoArk as a one-off design but rather they are trying to market the product to a wider audience. The concept has a large marketing value for the company as they not only retain the rights to the product but they are the only architectural firm qualified to specify it. This gives Miniwiz a unique advantage says Huang, “We have to be the architect to brand our product; to market-place our product where it is visible”. Projects involving POLLI-Brick typically include contracts with an architecture/design and consulting fee and a material supply agreement. The POLLI-Brick is currently being used in a government project in the Shanghai Bun which Huang notes is one of the most photographed sites in China, “We are using it as a branding exercise.”

However, Miniwiz does not intend to keep the POLLI-Brick as a proprietary system. They are currently in the process of having POLLI-Brick permitted as a standard building material in Germany. Challenges include the flame retardant chemical which is banned in Germany as are certain VOCs that the polycarbonate sheeting off gasses. A redesign is underway but the team intentionally chose to introduce the product in Germany as it has some of the most stringent building codes.

Huang points out that the EcoArk was a ‘concept car’ that can be tailored to different product lines, “We are in the process of making complimentary materials that will make POLLI-Brick more interesting as a system”. These add-ons include custom shading devices and images applied to the exterior sheeting. While the POLLI-Brick needed to be eye-catching and iconic to gain marketing traction the same qualities could potentially undermine the goal of creating a sustained product market. While products are intended to be replicable most people do not enjoy replicated architecture. However, in the EcoArk project POLLI-Brick as a product was the primary feature of the architecture. Distinguishing the two could prove difficult. Huang notes the importance of the customized product lines in addressing clients and architects less inclined to use a system already showcased in another project. Ultimately the mass-produced POLLI-Brick structural panels would have a mass-customized skin ensuring each project retained a degree of uniqueness.
12. Conclusion

For Huang the greatest challenge in developing the POLLIBrick was not in design, engineering or even production; it was in communication. Despite the large amount of positive media attention the process has been an uphill battle in convincing the typically conservative building industry to accept a new innovative approach. EcoArk Construction Chief Lin Kuo at first thought the idea was a joke adding, “The concept sounds nice and fancy but if it were carried out in reality it would be a very long process.” Construction Engineer and President Chan-Fong Cheng thought the idea was ‘crazy’ considering his forty years in the construction industry, “But I understand that young people always enjoy the challenge of carrying out crazy ideas.” Even after the EcoArk demonstrated the viability of the product Miniwiz has faced stiff opposition from conservative industry thinking in Germany. Huang notes, “We had to do a lot to convince the German engineers even to think twice before rejecting the idea out of hand.” While innovation is enough in developing consumer electronics like the Hymini, in developing the POLLIBrick Miniwiz learned that innovation in building is often met with skepticism, and communicating the need and potential for a new product must also be paired with communicating its reliability.