REBUILD OR REDESIGN
BREAKING THE RULES IN DISASTER PREVENTION DESIGN

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1. INTRODUCTION

On May 20th, 2013, an EF5 tornado traveling more than 210 miles per hour ripped through the town of Moore, Oklahoma. Dozens of people lost their lives, many of them children. Hundreds more were injured, thousands of buildings sustained damage. On May 31st, 2013, El Reno, Oklahoma, 22 people died in the tornado that pounded the region, including three tornado chasers who died in their mission to observe the phenomenon. Several of the victims were swept away from a drainage ditch where they were seeking shelter by flash flood. This tornado had an astonishing width of 2.6 miles, which makes it the widest tornado on record worldwide.

The devastating effect of tornado is so painfully illustrated by these recent cases that as designers and scientists, we must ask ourselves: what can we do to prevent such tragedies? The dramatic increase in the number, intensity and damage associated with tornadoes and the apparent expansion and northward shift in the area affected has placed major metropolitan areas such as Chicago and its surrounding communities at greater risk. On the night of May 31st, 2013, an EF3 tornado was spotted near St. Louis, Missouri, a large Midwestern city. The notion that natural disasters will not strike large cities is a myth. Hurricane Sandy already showed the world just how vulnerable our great cities are to natural phenomena intensified by climate change.

Unlike hurricanes, tornados strike with very little warning – making proactive design the main protective option. Doing nothing and allowing our communities to be built up in a business as usual fashion invites disaster. Likewise, in the wake of a disaster, simply rebuilding what was there the same way as it was before merely sets the stage for an even greater future disaster. We believe that a cultural shift in the public mindset is a pre-requisite for any real adaptive change. We also believe that the design community is ideally positioned to expedite this cultural shift by facilitating the development of safer disaster-resilient communities. We can do it by doing what we do best, creating innovative solutions to society’s problems.

In this paper, we focus on the design for life-saving instruments during tornados. We start by analyzing the vulnerabilities of big cities and people in different structures. Based on these analysis, we build scenarios for design strategy. Using the theory of disruptive innovation, we draft a process for designing for disaster prevention.

2. VULNERABILITY ANALYSIS

2.1 VULNERABILITY OF BIG CITIES TO TORNADOS

Chicago and its surrounding metropolitan area are vulnerable to tornados. Numerous tornados touched down in the Midwest this past May and June. Moreover, although many government authorities are still reluctant to come forward and say so, the preponderance of the evidence clearly shows that climate-change is increasing this vulnerability. The frequency and size of severe thunderstorms and the intensity of the wind speeds and precipitation associated with them are increasing. These super cell thunderstorms are spawning a greater number of larger higher intensity tornados. The geographic area affected by tornados is expanding and extending northwards. The duration of tornado season appears to be expanding as well, starting earlier in the year due to a lengthening of the period of Spring instability of the atmosphere during the transition from Winter weather to Summer weather.

2.2 VULNERABILITY OF OCCUPANTS OF STRUCTURES TO TORNADOS

Many people live and work in structures that are not tornado-resistant and therefore unsafe (such as a mobile home). The deadliest tornado in the history of the US was the EF-5 tornado that struck Joplin, Missouri in 2011, killing 158 people. According to the *Joplin Globe*, 54% of the people who were killed by the disaster were staying in their residence. Fujita tornado intensity scale defines that EF-5 tornado could lift a strong-framed building off its foundation. Many of the public buildings in the Midwest, where tornados are most common, are vulnerable. The May 20th, 2013 EF-5 Moore Tornado destroyed the Briarwood and Plaza Towers Elementary School, as well as the Moore Medical Center. Seven children died in Plaza Towers. In many cases, public buildings with large open interior spaces, such as shopping malls or gymnasiums, may offer worse tornado protection than the basement or interior room of a private residence. In a small interior room, there are many supporting walls. So even if the roof is removed, these walls, which are supported by other walls, will not collapse and the smaller opening keeps large objects from falling in. Due to the interior location, occupants are also less likely to be exposed to flying debris. This factors combine to increase the chance of survival in small interior spaces. Due to the span of the ceiling and the lack of supporting interior walls, once the tornado removes the roof of a large structure, there is nothing to support the walls. Hence they are now free-standing and can be easily blown down too. The heavy debris falls down on the occupants. The City of Moore, Oklahoma is no stranger to large, damaging tornados. It was hit with an EF-5 tornado in May 1999. Clearly, we have to do something different. Simply rebuilding our communities the way they were before the tornado is unsustainable and does nothing to reduce their vulnerability in the future.

2.3 VULNERABILITY OF OCCUPANTS OF VEHICLES TO TORNADOES

In large cities, many people's work necessitates that they spend a significant amount of time in their vehicles (taxi drivers, delivery drivers, salespeople, etc.). Many commuters also who find themselves in rush hour traffic on a daily basis. In the case of a tornado, a vehicle is an extremely dangerously place to be. The impact of an EF-3, EF-4 or EF-5 tornado on vehicles and their occupants in slowed or stopped rush-hour traffic on area expressways and main arteries would be devastating. In the worst case scenario, tens of thousands of people could be trapped in gridlocked traffic with little hope of getting inside a substantial shelter to ride out the tornado. People with reduced physical mobility such as infants and toddlers, the elderly and the disabled or sick are even more vulnerable in this situation.

It is easy to understand that the occupants of vehicles are more vulnerable to tornados than the occupants of buildings. It all boils down to design. Buildings are designed to be stationary. Vehicles are designed to be mobile. Strong tornados can move, overturn vehicles, and even lift and hurl heavy trucks, at high speeds, for hundreds of yards. Violent tornados are known to have left vehicles in mangled, almost unrecognizable, heaps of steel and to wrap them around trees and other fixed obstructions. In addition, vehicle occupants are located close to windows and doors and thus can be sucked out of their vehicles or impaled by flying debris. Statistics confirm that the occupants of vehicles suffer a higher fatality rate than the occupants of houses and other fixed structures. Eight out of the 22 people who died in the El Reno tornado on May 31st, 2013, were inside of their vehicles, including the three tornado chasers.

3. GOVERNMENT ADVICE

The US Federal Emergency Management Agency (FEMA), the federal agency responsible for emergency management, the US National Ocean and Air Administration (NOAA), and the National Weather Service (NWS), the government's scientific agency responsible for studying severe weather and issuing tornado warnings both offer similar advice, which can be summarized as the follows:

1. Identify the official county tornado shelters near your home, your work and other places that you frequent. If there are none close by, identify the nearest well-built structure, preferably one with a storm cellar, engineer-designed safe room or basement. If the building has none, identify a place to shelter on the lowest floor and in the smallest interior room of the structure, away from exterior doors, windows and outside walls. Place as many walls between you and the tornado as possible.
2. Relocate to your designated storm shelter structure during the tornado outlook or tornado watch phase well before a tornado warning has been issued. Since a tornado watch is often issued hours before the severe storms that generate tornadoes hit, there is sufficient time available to evacuate to a stronger shelter. Evacuating during the outlook phase is even better, since the outlook phase generally provides at least a day's advance warning that possible tornado weather is on the way.
3. Enter your sheltering space of your designated tornado shelter as soon as a tornado watch is issued or whenever the weather seems to indicate that a tornado might be present. Be sure that you are able to get into position within this space within minutes after a tornado warning is issued. Otherwise, you will be placing yourself at risk. Once inside, protect your body with whatever you have available: get under a sturdy piece of furniture such as a work bench and cover yourself with pillows, cushions, sleeping bags, a mattress or blankets; wear helmets (such as those used for bicycling or other sports), pants, long sleeve shirts and sturdy boots (to protect yourself from flying debris and to prevent further injury when you have to dig yourself out after the tornado passes by).

FEMA further advises people to who find themselves in vehicles that are in the path of an approaching tornado to do the following:

1. Observe the trajectory of the tornado and attempt to avoid it by driving perpendicular to this trajectory and towards sturdy structures known to be or which could potentially serve as tornado

shelters. Do not attempt to flee from an approaching tornado by driving the opposite way. You could run into traffic or storm-impacted roads only to find that you are still directly in the path of the approaching tornado!

2. If you cannot avoid the tornado, get your vehicle out of the traffic lanes and off the road. Park and exit the vehicle and seek shelter in a designated tornado shelter (as detailed above). If a well-constructed structure is not nearby, seek shelter in a depression in the ground lower than the road surface (such as a drainage ditch). Get as far away from trees and cars as you can; they may be blown onto you in a tornado. Lie face down and protect the back of your head with your arms and available clothing. Avoid seeking shelter on overpasses, in underpasses or under bridges. They offer no extra protection against flying debris and doing so can also create deadly traffic hazards. Because these structures tend to funnel wind and debris through a narrow channel, sheltering in these areas has proved to be deadly in tornadoes!
3. If you are caught in your vehicle when a tornado hits, pull off the road, put the car in park, and set the parking brake. Remain belted in, and crouch as low as possible away from any windows. Place coats, blankets or other cushioning material over your head. Survival is not guaranteed!

4. DESIGN STRATEGY

While our government's advice is technically sound, it is often infeasible or impractical. What really happens during a tornado incident?

4.1 DISASTER SCENARIO

In an urban scenario, people already in their vehicles may become aware that they are in the path of an approaching tornado by observing one or by listening to their radios or using their cell phones. The tornado is approaching at an average speed of 30 mph and accelerating to speeds approaching 70 mph for brief periods. People try to avoid the tornado by attempting to drive out of its path. However, since everyone is trying to do the same thing, people find themselves stuck in grid-locked traffic. Gridlocked traffic moves at an average rate of 10-20 mph and it is sometimes much slower. At such speeds, people stuck in gridlocked traffic can't outrun the approaching tornado with their vehicles. Meanwhile, outside the city, in rural areas, drivers encounter other difficulties. An open road or field that would allow a vehicle to travel at a sufficient rate of speed to avoid an approaching tornado may not exist. Such is often the case in forested areas or in areas with significant topographic relief. Thirty mph seems slow on the highway but it is quite fast compared to the speed that a vehicle can maintain when traveling along a narrow logging road. Agricultural roads that dead end at a farm aren't of much help either.

4.2 ANALYSIS OF THE SCENARIO

One might ask, why can't I jump in my car and drive away and thereby avoid the approaching tornado? This was exactly what many drivers thought in El Reno, Oklahoma in the early evening of May 31, 2013, just a few days after the Memorial Day weekend. Oklahoma "Sooners" are no strangers to tornadoes. They have experienced more than their share. Because of the media coverage of the devastating EF-5 Moore, Oklahoma Tornado a few days earlier, many people became even more aware of the damage of tornados could inflict on their homes and decided to flee. This increased the traffic loads on the roads, making the gridlock even worse. It also increased the probability of traffic accidents. Besides being wide, the EF-5 El Reno tornado also had wind speeds in excess of 295 mph, making it the largest and most powerful tornado ever recorded.

Some factors that people usually do not understand about tornados when they are considering fleeing in vehicles to outrun approaching tornados is that a tornado may not even be visible until it is too close to the vehicle. Tornados are visible during the daytime only after they touch down and begin to pick up debris. They are essentially invisible at night since the moving debris cannot easily be seen, although they can still be heard. Many tornados are wrapped in rain and sometimes hail, further bringing the visibility down. While it is true that if the tornado is visible, far away, moving slowly, and if there are open roads free of traffic and debris leading away from the tornado, one may be able to drive out of its path by moving perpendicular to the path of the tornado. Unfortunately, these ideal conditions are rarely encountered. People often underestimate the amount of time that it will take to evacuate and get to a shelter because they discount the effects of adverse weather and increased traffic. In many cases, an approaching tornado moves towards the vehicle with a ground speed that is faster than the vehicle can travel. In addition, although tornados are steered by larger synoptic weather patterns and tend to maintain their general course over long distances (often tracking to the northeast), they can rapidly change directions over short distances. Moreover, tornados often appear in swarms. Even if occupants of a vehicle can “outrun” one tornado they may place themselves directly in the path of another one.

When a vehicle is stuck on the road, it may be difficult or impossible to get the vehicle off of the road because drivers attempting to avoid the approaching tornado are using the shoulder as an additional traffic lane. As a result, some people choose to remain in their vehicles. Unable to get their vehicles off the road, other people simply abandon their vehicles in the middle of the highway. The abandoned vehicles create traffic accidents and further contribute to traffic gridlock. Having left their vehicles, they hurry along the highway hoping to find an exit ramp or attempt to seek shelter in a drainage ditch next to the highway. Walking out in the open or attempting to find shelter in a drainage ditch adjacent to a highway jammed with gridlocked vehicles is even more dangerous than remaining in their vehicles. Vehicles on the highway can be overturned by the tornado and tumble or be hurled into the nearby drainage ditch. Drainage ditches rapidly fill up with water due to heavy rains that accompany tornados and the sudden flash flooding that subsequently occurs. Flash flooding kills and injures more people each year than tornados. Consequently, lying face down in a drainage ditch during a thunderstorm is not a very safe place to seek shelter.

For all these reasons, the conventional wisdom of jumping into your car with the intention of outrunning an approaching tornado more often than not turns out to be a terrible idea!

4.3 DISRUPTIVE HYPOTHESIS

We adopted the disruptive innovation process developed by Clayton Christensen (Christensen, 2013) and many other scholars as our design strategy. We set out to find and overturn the cliché in these tornado disaster scenarios and attempted to identify an opportunity to develop a disruptive product. As Luke Williams points out in his book *Disrupt: Think the Unthinkable to Spark Transformation in Your Business*

(Williams, 2010), when crafting a hypothesis for disruptive innovation, one must first ask: what do we want to disrupt? The design team zeroed in on a hazardous situation affecting a specific target customer – in our case a car full of commuters stuck in rush hour traffic who are directly in the path of a strong destructive EF-3 tornado and are unable to get off the highway and find shelter in a suitable structure. We ask: what are the established clichés surrounding this situation? We must identify the key assumptions, beliefs and values that underpin these established mental models in order to find the opportunity to disrupt. Based on our analysis above, we came to the conclusion that avoidance and evacuation are generally an infeasible option in a tornado incident and shelter-in-place is the only feasible option. What if instead of fleeing, we stay put in the tornado? What if instead of finding a stable and solid shelter, we create a mobile and temporary shelter with a flexible but impenetrable skin?

4.4 PRODUCT POSSIBILITY

After further development of this seemingly impossible, infeasible, and unreasonable concept, we established the following design criteria:

- The product must be easily stored in a vehicle;
- The product must provide an adequate level of protection for human body against flying debris;
- The product must be easy to use and set up in seconds, even in high winds and inclement weather conditions;
- The product must be able to anchor itself so it will not be lifted off the ground by strong wind and should resist being swept away by a flash flood.
- The product must prevent its occupant from drowning.
- The product must be easy to reopen to allow the occupants to exit after the tornado has passed.
- The product is designed to offer protection from flying debris. It will not be designed to protect occupants from being crushed by heavy objects (such as hurled vehicles or falling trees).

Our product is designed to reduce but not eliminate all risk. Since only limited added protection is being offered, these criteria seem to be achievable and not that outrageous after all.

4.5 PRODUCT CONCEPT: NadoPod

Our initial concept could be described as a pea-pod shaped “cocoon”, a capsule that might hold one adult individual and an infant or small child. It is collapsible, it could be quickly fold out. The pea pod shape was chosen because it would allow an adult the option of lying in whatever position works best for them. They could, for example, lie on their side in a fetal position with their knees up and hold a child against their body. If no child is present, they might chose to lie down. In addition, both ends of the pod will be attached to strong but flexible steel cable equipped with a Carabineer safety spring D hook clip (similar to those used for climbing) to enable the product to be secured to an immovable object such as a post. As possible variation that we are investigating is the NadoPancho, a soft body armor in the form of a quick-donning poncho. When in an emergency situation, family members need to travel and stay together. Since this product must accommodate both children and adults it must be produced in a range of sizes. So this product should provide family and individual sizes. The NadoPancho will have the same cables and clips as the NadoPod. It will also have a fold out piece at the bottom of the poncho that can zip together over the feet of the wearer, essentially turning the NadoPoncho into the NadoPod.

The key technology that might make the product work is a liquid gel known as Shear Thickening Liquid, a new material that has been developed by several companies and organizations such as BAE Systems and the University of Delaware in collaboration with the US Army. We are considering using this gel for the outer layer of the product. The fluid has special particles that are freely suspended. The particles collide when the fluid is disturbed, which creates a resistance to the disturbance. The material remains fluid during normal body motion. However, when the force of the disturbance is great enough, the particles will then actually "lock" together. This material is currently being tested on body armor. When a bullet hits the material at high speed, the fluid absorbs the impact energy and hardens extremely quickly. The material is also light weight and can be woven in between other fabric. These characteristics make it an ideal choice for the outer layer of this product to provide the protection against flying debris generated by a tornado. Granted, no garment or tent will protect you when a flying vehicle lands on you, but hail stones and other small flying debris will not harm whoever is inside of the product.

Both products could be used by people who take shelter inside of a structure as well. A tornado is associated with extremely low barometric pressures. This center of low pressure is responsible for the high winds and the suction effect associated with tornados. Due to the large difference in air pressure inside and outside of the house, tornados literally cause the house to explode outwards. While this debris will be lifted away from the house, debris carried by the tornado from elsewhere might eventually land on survivors who remain inside as the tornado passed by. This product would provide additional protection against this flying debris.

These products are still in the conceptual stage of development. We intend to experiment with various shapes to attempt to find one that when subjected to high wind speeds, the wind will push the product down to the ground, making it more difficult to be lifted off the ground.

4.6 USER SCENARIO

It is tornado season. A family of three is traveling along the highway in a city. They hear the tornado warning and realize the tornado is heading their way. With only minutes to reach a shelter in a part of the city that they are not familiar with, they decide to pull their vehicle off the road, park the vehicle against the guard rail, turning the front wheels toward it and set the emergency brake. They pull out their NadoPods from the trunk (or don their NadoPonchos) and secure their NadoPods to the guard rail, zip them up and shelter in place on the back side of the guardrail placing their parked vehicle and the guardrail between themselves and the highway. A strong tornado reaches them and drops hundreds of debris on top of their pods, which quickly harden with each impact. The wind moves away within seconds. The family emerges from the pods to find their vehicle has been moved by the tornado but since it was parked against the guard rail, it did not overturn. All of the vehicle’s windows are shattered and it is pretty banged up, so is the NadoPods. But it did the job of protecting the family from heavy falling debris lifted and turned by the wind.

4.7. CONCEPT VALIDATION

Currently the NadoPod and NadoPoncho remain concepts. We are working to secure the funding for this project. We will need funding to secure the licensing of the Shear Thickening Liquid, for prototype fabrication, and for wind tunnel testing. We plan to seek crowd funding.

5. FURTHER RESEARCH

The above process clearly shows that designing for disaster prevention needs collaboration from scientists and designers. In addition, a cultural shift of mindset must occur in the community affected by disasters to achieve any meaningful and practical solutions. There has been much development of strategies, as well as ancient wisdom, in dealing with disasters. We feel that an online crowd sourcing platform is needed to achieve our long-term goal of building a disaster-resilient community. The platform will become a central hub for collecting and hosting information of disaster prevention, user scenarios, and conceptual designs. Much like the car design crowd sourcing platform built by Local Motors, this platform will invite people from all over the world to brainstorm ideas and create prototypes. Then it will organize the commercialization of the most promising ideas.

6. CONCLUSION

Designing for a disaster-resilient community has been our ongoing long term research project. This paper uses a concept developed for protection in a tornado as an example to illustrate our design process, which could be summarized as follows:

- Identify a particular hazardous emergency situation that needs to be addressed;
- Analyze the vulnerabilities of a specific target group of people affected by this particular hazard;
- Create realistic scenarios of how the affected target population actually respond in an emergency situation when confronted with the hazard;
- Analyze the success and failure of the current recommendations. Identify the underlying mental models and assumptions underpinning the current recommendations;
- Build a disruptive hypothesis;
- Create parameters for solutions based on the hypothesis;
- Tackle each essential feature of the solution and search for the ideal form;
- Build prototype to test and validate the solution.

This process is iterative and easy to apply.

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