Creating an Origami Shelter Prototype for Migratory Populations of Himachal Pradesh, India

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Abstract

Within Himachal Pradesh, India, there is a scarcity of proper temporary shelters built to withstand rough weather patterns, creating difficulty for the diverse, transitory populace. With the goal of creating a marketable, portable shelter, we investigated using origami as a tool to improve shelter quality. We have collaborated with IIT students and professors to understand the stakeholders' shelter constraints using interviews. Based on their responses, we designed and built a prototype that will address both origami and their needs.

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Authorship

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Table of Contents

Executive Summary: Creating an Origami Shelter Prototype for Migratory Populations of Himachal Pradesh, India

Temporary shelters in Himachal Pradesh

In many countries throughout the world, migratory populations have a pressing need for safe and comfortable shelters. In northern India, such populations include Gaddi herders, homeless, and migratory workers. These groups have disparate needs, so designing suitable, temporary housing is a challenge. The significant environmental considerations for both rural and urban users indicates that those that lack proper housing can find life difficult. The disparate requirements of families vs. trekkers or Gaddi shepherds vs. semi-migratory construction workers means that each group generates its own checklist for suitability. In harsh environments, inadequate shelter means having to endure biting cold, scorching heat, and monsoonal rains.

The collaborators for our prototype's design were individuals who could benefit from light and portable housing. We identified parameters that could meet not only the needs of semi-nomadic herders, but also those of construction workers on a three-year stay. Migratory shepherds often travel to remote or high altitude sites and live in tarps that are not entirely suitable for the weather pattern. The Gaddi, a tribe of shepherds in Himachal Pradesh, India, migrate up and down the sub-Himalayan mountains throughout the year (Figure 1) (Chakravarty-Kaul, 1998).

Figure 1. A Gaddi herder with his goats.

The geography and climate in this terrain can be taxing, including temperature ranges from -20° C to 40°C (-4°F to 104°F) and slopes up to a 70% grade (35° angle)(Kaushal, 2001).

Temporary construction or agricultural workers, on the other hand, need shelters that are adaptable enough for long-term stays. Construction workers are often confined to plastic tents or tin shelters near the worksite and settle at their current job until the work is finished (Figure 2) (Kumar, 2013).

Figure 2.Tin structure destroyed by wind.

These structures run the risk of damage from weather and construction debris. The workers often travel greater distances and also move from site to site over months or years (Kumar, 2013). Their average pay is low (Maiti, 2008), which forces them to routinely rely on makeshift plastic covers, rubber, or metal sheets to make their shelter with (Kumar, 2013). In addition, temporary workers often bring their families and children, exposing them to the hazardous work environment.

There is an opportunity to develop a fellowship with the transitory populations and to share ideas for creating better shelters that address their needs. The goal of this project was to create a marketable temporary shelter for diverse migratory populations. To meet the needs of the users in our stakeholder group, we turned to origami as the basis of our design.

Origami, the art of folding paper, is an excellent method for creating different shapes while maintaining a stable structure. It offers a wide variety of properties from the different shapes that can be constructed. These qualities will be discussed in the next chapter to delve into the practicality of origami.

To meet our goal of an origami-based design, we established three objectives: 1) to assess stakeholder requirements by analyzing their shelters, environment, and needs, 2) to identify accessible, efficient, affordable and environmentally sustainable materials, and 3) to map origami principles onto stakeholder criteria to distill design requirements. Once these objectives were met we were able to recommend and test a design that our stakeholders would want to use. By providing temporary and portable origami shelters that meet the particular needs of moving populations, we can improve quality of life and overall well-being with a product that is resilient, useful, and adaptable.

Using origami as a basis for designing shelters for migratory populations

Temporary shelters must be designed to be light, compact yet expandable, and satisfactory to diverse needs in their respective environments, thus investigating the versatility of origami structures has allowed us to see its potential to address broad needs. Origami can be useful in applications of engineering the shelter in terms of deployability, strength, insulation, ventilation and wind resistance. These capabilities can be found in different folding strategies that can unleash an array of possibilities in creating a shelter.

Origami can enhance a temporary shelter because folds can be used for practical purposes such as deployability (Schenk, 2012). The most important quality of origami for shelters is that a two-dimensional foldable material is transformed into a three-dimensional structure useful for compacting and transporting, which are critical attributes for temporary shelters. Origami allows a structure to self-generate whereas tents sometimes require additional parts for assembly. Deployable structures can allow the user to erect their shelter easily. In fact, this feature allows the structure to be used by an unskilled person. Furthermore, the structure can be easier to compact, carry, and store (Schenk, 2012).

To best understand the capacity for origami shelters, we evaluated the physics of fold design, including the reverse, valley and mountain folds. The first deployable origami model we explored is shaped and behaves like an accordion, with a folding technique called the reverse fold. The reverse fold can be used repeatedly on a sheet to formulate zig-zag and trapezoidal patterns from the creases. This quality is illustrated in Figure 3.

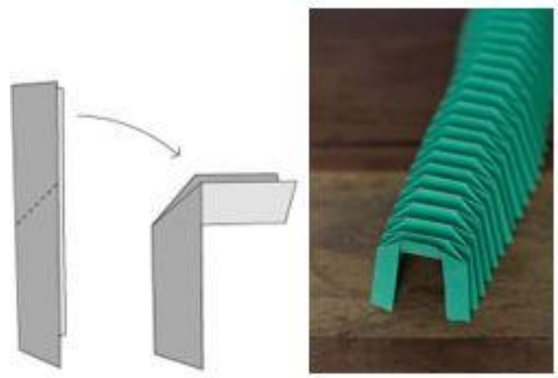

Figure 3. Reverse fold (left). Application of reverse fold in deployable structure (right).

It is possible to add more folds to the structure to expand the size. Thus, with the ability to compress, the structure can be smaller or larger, allowing for versatility in size.

A second folding pattern uses triangular structures. Triangles in nature have incredible strength because the sides cannot be misshapen when pushed or pulled, like other geometric shapes, and are often used in architectural design for maximum support as seen in truss bridges. Truss structures are made of triangles joined together and are often used to strengthen cantilever bridges (Bridges-Truss, 2015). The shape of the triangle can be seen through the Diamond, Diagonal, and Herringbone folding patterns, sufficient for improving the overall strength of the structure as illustrated in Figure 4 (Buri, 2008).

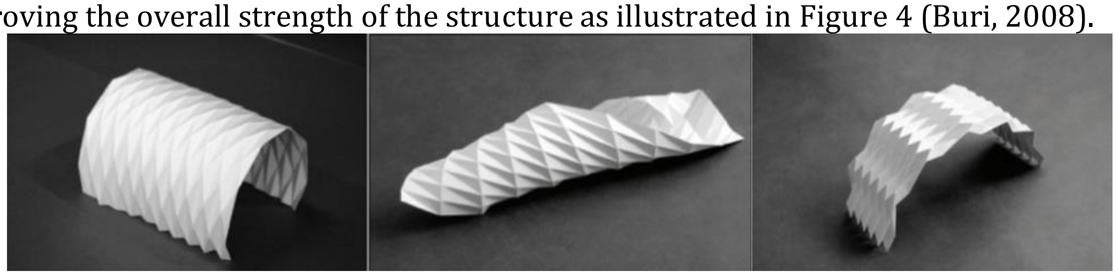

Figure 4. Diamond, Diagonal, and Herringbone folding patterns seen from left to right.

These patterns can be made from modifying the reverse fold or creating mountain (outward) and valley (inward) folds. Triangular folds can be applied to the shelter to decrease the need for supporting poles, hinges, or other supporting parts for strength, as some modern tents would use.

A third dimension in fold patterns enabled us to consider pockets. In fact, origami engineering inspired Joe Gatta (Dillon, 2007), a student from University of Oxford, to develop an emergency shelter that has one origami-like plate assembly in between two layers to greatly increase strength and thermal insulation. Figure 5 shows the emergency shelter known as "Plate House."

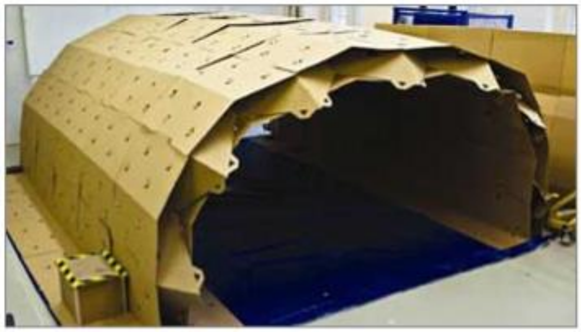

Figure 5. Multi-layered origami shelter using trapped air pockets for insulation.

In structures, insulation can be done in different ways such as by layering insulating materials over air pockets to trap in heat (Dillon, 2007). In this case, the underlying fold pattern can create those air pockets. Any tessellation of diamonds, squares or zigzags can be used as air pockets to retain heat, as seen previously in Figure 4. Thus, this shows how origami can be an advantage to the design of a structure because of the variety of ways that it can trap heat based on folding patterns.

Considerations for ventilation can also be found with origami. Preliminary research revealed the capacity for pop-ups that can change airflow. This is a different form of origami, known as kirigami, or the art of cutting paper (Origami-Resource-Center, 2015). Pop-ups are created by making a 90° fold on a sheet of paper and making two slits to create a pocket for the paper to extrude (Origami-Resource-Center, 2015). Pop-ups can be useful for not only creating deployable structures but also for adding openings to serve as windows. This can be illustrated in Figure 6.

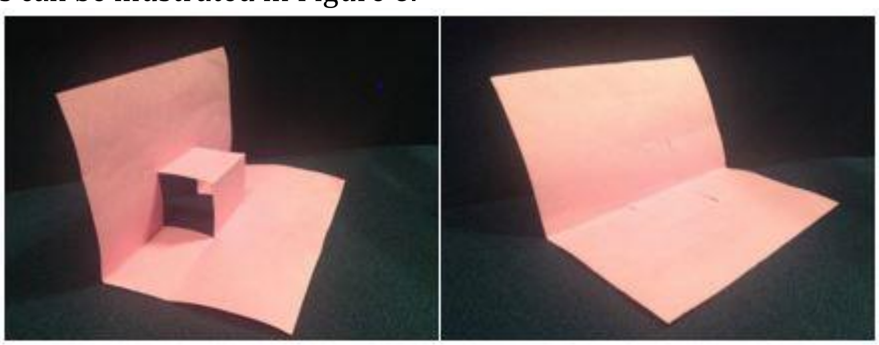

Figure 6. Pop-up origami, open (left) and closed (right).

If there is a corner, slits can be made to push out the material as seen in pop-up books, allowing the air to flow through. Therefore, air flow design can be dependent on origami structures as well.

Finally, the overall shape of an origami structure can affect its wind resistance. Origami has versatility in shape, where the structure can be triangular, square or round. In this case, a round structure has been proven to be aerodynamically more windproof than a square or a rectangle (Full Circle Shelters, 2015). An example of the rounder shape of origami can be seen in Figure 7.

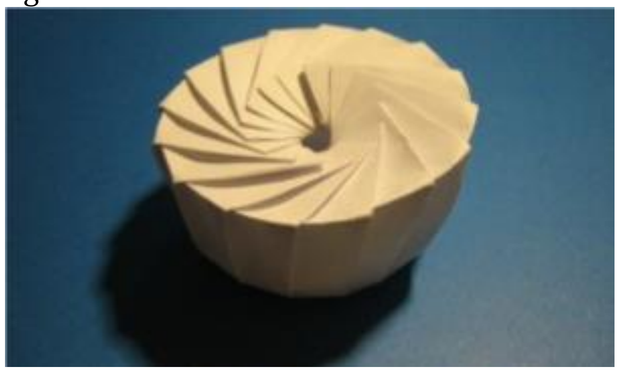

Figure 7. A rounded origami structure.

When wind gusts hit a round shelter, the airflow moves smoothly against the structure, which prevents destructive gradients of air pressure that square structures would produce. Therefore, origami can be tailored to different shapes to help serve this purpose as well.

In architecture, origami has been applied to structural design for many of the reasons that have been previously mentioned. The key importance of designing an origami shelter is not only to design the structure, but also to use materials that will preserve these qualities demonstrated easily in paper. One early example of this application is Herbert Yate's shelter, the Plydome, designed for migrant farmers (Life, 1967). The structure was designed with panels made of Kraft paper, polyurethane foam, and polyethylene so that it could be waterproof, lightweight, fire-resistant and self-insulated, as seen in Figure 8.

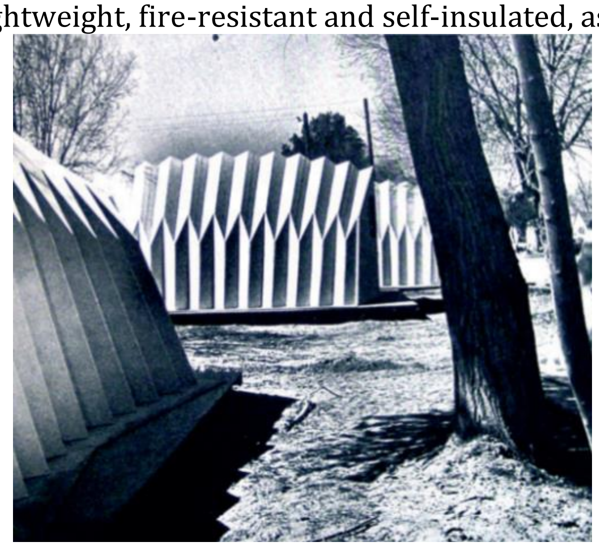

Figure 8. Herbert Yate's Plydome.

While the dimensions were at a larger scale, and the structure was not portable, the work of these architects indicates the capacity of origami as a design framework.

A modern architectural design that we reviewed was Alastair Pryor's (Estes, 2014) polypropylene emergency shelter, named the Compact Shelter because it was designed to mimic qualities of origami's deployability. This picture is shown in Figure 9.

Figure 9. Pryor's polypropylene emergency shelter.

This is a reasonable model for our project because Pryor designed the shelter to be constructed in less than two minutes, showing the ease of construction for the shelter. Also, the shelter's thickness reduces to three inches and weighs 35 pounds, making it easily portable (Estes, 2014). Therefore, this structure exemplifies portability and compressibility in a temporary shelter and serves as a helpful guide to showing these qualities in our shelter.

In sum, origami is a formidable tool for designing temporary shelters because it has potential to create a suitable temporary shelter with diverse techniques using its folding patterns. We now know that origami not only serves aesthetic purposes but also serves practical purposes. This has helped us to understand how to use these properties in incorporating a suitable prototype for the stakeholders.

Methodology

The goal for this project was to create a marketable origami structure prototype that could be customized to any migratory population. In order to meet this goal, we identified three objectives. We wanted 1) to assess current stakeholder requirements by analyzing their shelters, environment, and needs, 2) to identify accessible, efficient, affordable and environmentally sustainable materials, and 3) to map origami principles onto stakeholder criteria to distill design requirements. These objectives can be seen in Figure 10, with the required steps to meet each objective.

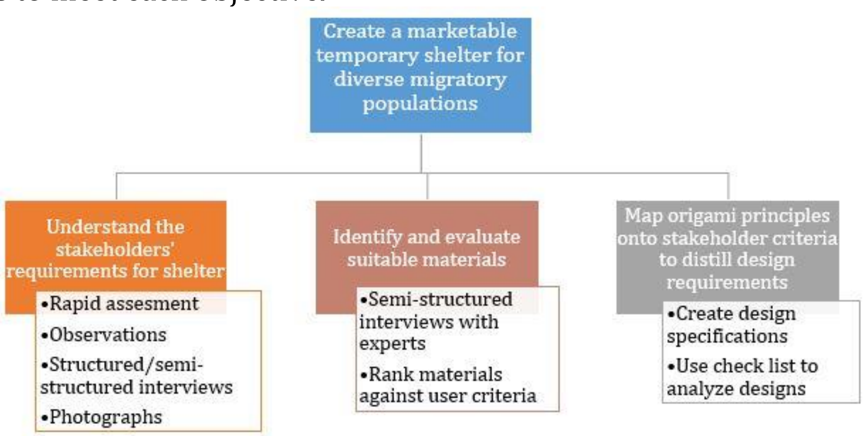

Figure 10. Methodology overview.

In order to understand the stakeholders' needs, we conducted a series of structured and semi-structured interviews and rapid vulnerability assessments. The structured interviews were conducted with construction workers in the IIT-Kamand's South and North Campuses, trekkers, and Gaddi herders, using a sample of convenience to identify potential users for temporary shelters. The questions focused on environmental conditions, travel patterns, advantages and disadvantages of shelters currently in use, and overall interest in a new shelter prototype. This was done in order to understand how to tailor the shelter design to their needs including weight, cost, and size. We also conducted semi-structured interviews with lower income stakeholders, specifically those identified as homeless and those living in slums in order to ask about affordability. Rapid vulnerability assessments can identify and prioritize vulnerabilities (Birkmann, 2007), and we used them to do so for temporary workers, the homeless, and slum residents.

Our second objective identified suitable materials. Our interviews yielded criteria for what materials are essential for the stakeholders such as being waterproof and lightweight. We conducted research for materials, including ones used in existing deployable shelters, to ensure that the materials found will be sufficient based on the criteria. To obtain materials that are accessible and affordable, we conducted semi-structured interviews with both a civil engineer and an experienced trekker to gain information about the necessary materials for constructing a prototype.

Our final objective was to map origami principles onto stakeholders' criteria to distill design requirements. In order to meet this objective, we researched origami methods that are practical for designing shelters. We analyzed which qualities could be useful for the stakeholders. We produced a Venn diagram that organized overlap of all of the criteria in terms of material, origami properties, and stakeholder needs. From there, we built a checklist of each of the attributes that could inform our preliminary designs and prototype to best fit our stakeholders' needs.

We gathered materials from local hardware stores and vendors to adapt in the Mechanical Workshop at the IIT. We used a test protocol that we constructed based on the design specifications listed previously. This way, we could evaluate the durability, foldability, and waterproof resistance, among other attributes, to ensure maximum performance for stakeholder feedback.

Results and Discussion

Here we present the results of our 3 objectives.

Objective 1: Stakeholders' needs and constraints

We interviewed 18 individuals to obtain the necessary shelter information from our stakeholders. Of these, seven were construction workers, two were shepherds, four were trekkers, two were slum residents, and two were homeless.

The first region we targeted was the North and South Campuses of IIT-Mandi to conduct interviews with construction workers. Their responses are recorded in Table 1.

Table 1. Construction workers' interview responses.

Construction worker responses
• Willing to pay to ₹1,200- 20,000 • Willing to carry up to 30kg • Move every 1-3 years • Required Area for shelter: $60ft^2$ to $100ft^2$ • Five live in mountainous terrain; two live in cities

By conducting a rapid vulnerability assessment, we recognized that the workers at the North campus live in tin and wooden structures. One worker allowed us to inspect his home more closely. It was constructed of tin sheets with a moldy wooden frame. There was little ventilation and light for the shelter3 since there was only one small window. To satisfy the need for proper lighting, the worker had a light bulb turned on even during the day. Additionally, the shelter contained shelving, a bed, and a cooking area with a space of around 60 ft^2. At the Kamand Campus, we observed that the shelters were made with either brick or tin sheets, with a few that have placed branches on their roofs to hold it down in heavy winds. The construction workers' children were present, some at the side of their parents working in an environment filled with dust and high potential for injury from bricks, rebar, and other construction materials.

We visited Mandi town to interview two residents of the slum and three homeless individuals that were staying in the Tibetan market across the street from the IIT-Mandi campus. Table 2 shows the responses of the slum population.

Table 2. Slum residents' interview responses.

Mandi slum residents constraints
• Move once a month • Willing to carry 15kg • Require shelter larger than $60ft^2$ • Live in groups of five

The two residents in the slum neighborhood reported that they move about once a month depending on their work. We did not ask how much they would be willing to pay. From our rapid vulnerability assessment we observed that there was a lot of trash with glass and excrement around the area. The tents were made of tarps and scrap plastic with wooden frames.

Responses from the three homeless individuals can be seen in Table 3.

Table 3. Homeless people's interview responses.

Tibetan Market homeless constraints
• Value a shelter with roofing and insulation • Move everyday

The homeless reported that they move every day because the market where they sleep opens for business during the day. They live in groups of four people in each market kiosk, but for the purpose of data analysis to determine our origami shelter size, we marked them down as living individually. The assessment concluded that these kiosks give them no protection or privacy. Just as before, we did not ask about how much they could afford and they all made no comment on how much they would be willing to carry.

To broaden our stakeholders to include migrant shepherds, we interviewed two Gaddi herders, one at the IIT Kamand campus and the other on a mountain between the North and Kamand campuses. Their responses can be seen in Table 4.

Table 4. Gaddi herders' interview responses.

Kamand valley Gaddi herder constraints
• Move every 2-3 days
• Live in shelters of 3-4 people
• One willing to pay ₹1,000; the other between ₹3,000-4,000
• Shelter must be waterproof
• One herder would carry 5-10kg but the other does not care about weight because they have a horse
• Ventilation is a concern for one of them while the other is concerned about deployability.

They both travel with animals on mountainous terrain. An assessment was not conducted on the herders' shelters, because their shelters were not set up when we were with them.

Finally, we interviewed four trekkers. Their responses can be seen in Table 5.

Table 5. Trekkers' interview responses.

Trekker constraints
• Move daily
• Shelter must be waterproof
• Three out of four mentioned that the shelter must be anchored and floored
• One said shelter must be 4ft tall and 18ft^2 in area
• One required good ventilation
• One is willing to pay ₹3,000-5,000

From the interviews we learned that they typically move daily while trekking in mountainous terrain. Just as with the Gaddi herders, an assessment was not done on their shelter, because at the time of the interview, they did not have their tent set up.

The data from all of the stakeholders can be seen in Table 6 and Figure 11. Table 6 is an overview of the interview responses from our stakeholders while Figure 11 shows the properties that found as key to a good shelter.

Table 6. Overall data ranges for interview responses.

Characteristic	Response Range Value
Time in one location	1 day-3 years
Number of people in one shelter	1-6 people
Weight willing to carry	5-30kg
Amount willing to pay	₹500-20,000

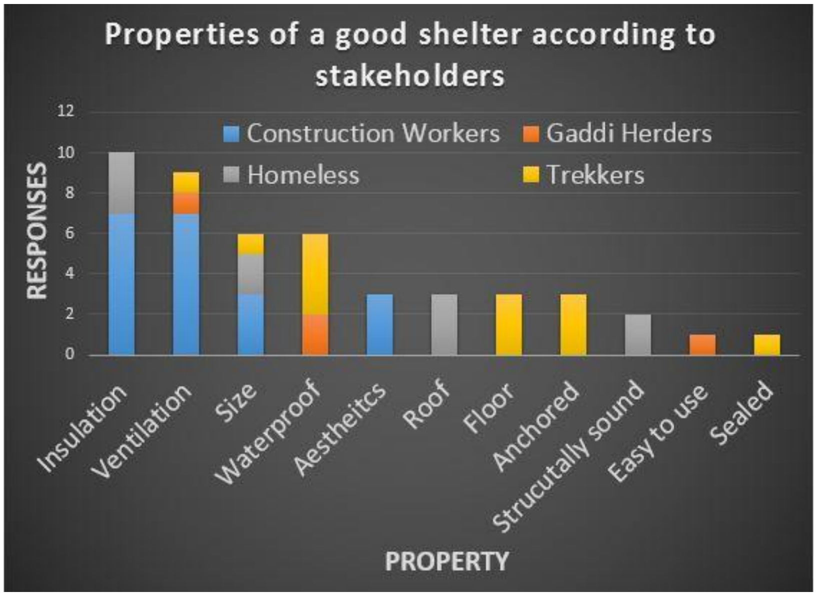

Figure 11. Properties required in a good shelter.

The table clarifies that the shelter must be able to satisfy these parameters based on the responses that we have collected from the stakeholders. In sum, the responses have helped us to determine specifications of the shelter in terms of size, cost, weight, and durability. The graph shows the key properties. The top three responses are insulation, ventilation, and size.

Objective 2: Identifying suitable materials

We observed that the stakeholders had a wide variety of materials to construct their shelters. The construction workers used tin sheets, wood, and bricks to have longer lasting dwellings, and likely also due to the proximity of building supplies to their site. The Gaddi herders reported that their shelters are made of their own clothing, plastic sheets and wood. The trekkers use plastic sheets and wood, and lastly, the slum populations use plastic sheets, wood and scrap materials, such as old tin sheets.

After assessing the materials commonly used, we also evaluated readily available materials. We found that cardboard can be found or repurposed from industrial waste and is a good insulator (Swanson, 2015). We also identified plastic tarpaulin, Velcro, and mesh in local vendors in Mandi that can achieve weather resistance in a shelter.

Plastic tarpaulin will serve as a waterproof covering and flooring of the shelter. Also, it is normally used in temporary shelters, is lightweight, durable, flexible, rot and weather-proof (Tarpaulin House, 2012). Velcro was used to seal the door and windows, while mesh was used for the windows to help seal out insects and animals. Thus, these materials were suitable for constructing the origami shelter based on their functionality.

Objective 3: Map origami principles onto stakeholders' criteria to distill design requirements

We combined origami properties with the needs of the stakeholders and materials to see overlap. From the interviews, we created a list of criteria that satisfy the design needs for a shelter. Each of these considerations is expressed in Figure 12.

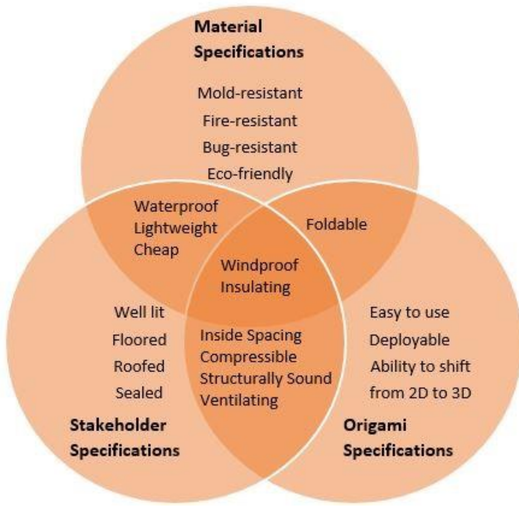

Figure 12. Design specifications Venn diagram.

Table 7 shows the final design specification in detail for the shelter as a whole.

Table 7. Shelter design specifications.

Property	Definition
Waterproof	Sustain 1270mm of rain
Insulation	Hold 19°C
Wind Resistance	Withstand 9.6km/hr
Mold Resistance	Must be waterproof
Eco-Friendly	Must be recyclable
Bug Resistance	Completely sealed
Lightweight	Less than 5kg
Affordable	Less than ₹1,000
Ventilation	Air flow through structure
Well Lit	Brightness must be 100 Lux
Compressible	No dimension can exceed 120cm when collapsed
Ease of use	Less than 5 min. to set up

We used these measurable criteria to further determine our prototype. We created a checklist. The checklist has some of the design specifications that are dependent on structural design that would correlate to origami and stakeholder specifications. The (x) indicates that the structure is satisfactory in this area, while the (-) indicates it is not. Table 8 presents the results of this synthesis.

Table 8. Design checklist.

Property	Dome	Accordion House Pavilion	U-Pavilion	Diamond Fold
Waterproof	x	x	x	x
Insulating	x	x	x	x
Wind resistant	x	-	-	-
Bug resistant	x	-	-	-
Lightweight	x	x	x	x
Affordable	x	x	x	x
Ventilation	-	x	x	x
Compressible	x	x	x	-
Easy to use	x	x	x	-
Sheds water	x	x	-	-
Total points (out of 10)	**9**	**8**	**7**	**5**

From this checklist it was determined that we would build full-scale prototypes of the dome and accordion house pavilion since they scored the highest.

Discussion

Our data revealed some surprises while confirming some of our predictions about stakeholder needs. We identified new trends in terms of migration patterns. We also found a wide range of responses when asking about affordability, migratory patterns and vulnerabilities that we had not predicted before our interviews. For example, construction workers could afford up to ₹20,000 on a shelter. Though we expected they could pay some amount, we did not expect that the price would be so high. At the same time, the homeless and slum residents need a shelter that is low cost or subsidized for them to make the shelter affordable. In order to provide these subsidies, we considered reaching out for NGO support, but we were informed that funds would not be available to support the shelter. This forced us to consider the difficulty in setting a reasonable price range for all stakeholders. The range must balance amenities and quality with affordability. We made the decision to prototype a version that will have some unit cost, in order to test a range of materials and sizes.

We also found that migration patterns factored into the lifestyle requirements of the shelters. Construction workers' shelters were ultimately outliers in that they are semi-permanent, which greatly affected the trends in our data. For example, these workers cook in their homes, need storage options inside the structure, and bring in full-sized beds. Their shelters are closer to second homes to the occupants, than they are temporary shelters. Contrary to construction workers, the other stakeholders in our study were more transient. They cooked outside and did not carry furniture, meaning that the shelters are used mostly as a sleeping and sitting area. Most of these more transient stakeholders require a shelter that can be transported daily or monthly, so the temporary quality of the shelters has more importance.

Overall, the qualities that stakeholders value most are insulation, ventilation, and a suitable shelter size. This fact is not surprising because the weather in the area tends to have cool winters and hot and rainy summers, making weather protection highly important in a shelter. In fact, the structures that the stakeholders currently use have this issue because there were vulnerabilities in both material selection and structural design. Thus, durability and weatherproof materials are important.

From the constraints given by the stakeholders and our research, we realized that finding materials would be challenging, especially when considering origami within the design. One obstacle that we faced in our search was accessibility of suitable and affordable materials. The materials that we would find online were either not available in India or would take too long to ship from other states. Moreover, we realized that the materials that we obtained could be found easily in Mandi to replace or repair the structure. Another obstacle we faced was finding a foldable material. At first, we wanted to fold the material to create the entire structure, as we have seen in previous inventions. However, we could not find an available material to solve this issue. Instead, we found a different strategy to mimic the creases in the shelter that we have created. Hence, as a solution, we decided to construct the shelter out of corrugated cardboard panels and plastic tarpaulin to satisfy these qualities.

Project Outcomes

Our research resulted in three outcomes:

1. A full scale prototype of our dome design.
2. A small scale prototype of the pentagon design.
3. Confirmation that origami is a feasible idea to apply to structural engineering.

1. *Full Scale Prototype: The Dome Structure*

The prototype that we built can be seen in Figure 13.

Figure 13. Full scale dome prototype.

The dimensions are 104cm for the height and 194cm for the diameter. We chose this design based on the results from the checklist mentioned earlier. The prototype is made from cardboard and plastic tarpaulin, with Velcro attachments. The prototype is circular because it will help with wind resistance. It also possible that another dome structure can be attached to increase the size. The creases in the roof allow water to runoff so that there is no accumulation of rainwater. Also, there is an attached floor to help the inside stay clean and add protection from insects and rain for the user. The Velcro is used to attach the floor so it is easy to remove. There is also an entrance with Velcro so that it can be sealed to address bug resistance and improve insulation within the shelter. After building the structure, we conducted two informal tests outside to see whether the structure would be a suitable shelter against the weather conditions. It can withstand rainfall and it has been confirmed that the inside has stayed completely dry. Also, the shelter was comfortable in temperatures of 20°C -23°C. In both trials, the shelter took two minutes to set up and compress. When folded, the structure looks as it is in Figure 14.

Figure 14. Full scale dome prototype in compressed form.

There are backpack straps attached for easy transportation. When compressed the structure is 23cm thick and 158cm long. The entire structure weighs 15kg. Figure 15 displays how the structure gets to its collapsed form.

Figure 15. Shelter transforming from popped up to compressed.

2. Small Scale Prototype: The Pentagon Structure

Since the pentagon structure had the second highest scoring in the design checklist, we wanted to investigate the feasibility of using it as a possible prototype. To waste less materials, we created a small scale version. We used the same materials that were mentioned in the first project outcome. This can be seen in Figure 16 below.

Figure 16 Small-scale Pentagon Structure

Panels with reverse folds were attached to create the creases of the structure, just as the dome structure was built, however it can be difficult to compress because of how the creases are arranged. Though it behaves like an accordion, the structure is rigid when it comes to folding it in half to condense the size. If it was in a larger scale, the compressed shape would be an issue for the user because the cross-section of the structure would be too large to carry. Thus, we concluded that this structure would not be a suitable prototype to build in a larger scale.

3. Confirmed Feasibility of Origami in Engineering

After creating the full-scale model of the dome prototype, we confirmed that origami can in fact, be a useful tool in shelter design. The main features that we have witnessed while examining our prototype is that it can achieve stability in a structure based on folding patterns, be compressible for better storage, and be deployable for ease of set up. From these examples, we can confirm that origami can be useful for structural engineering and provide an easier way to construct a shelter as well as improve the shelter's overall quality to the user.

Recommendations for Future Projects

There is room for improvement in the design of the shelter. The materials that we obtained were out of convenience because of time constraints and the difficulty in delivering from long distances. If ordered sooner, corrugated plastic sheets can replace cardboard to significantly reduce weight. Furthermore, the need for tarpaulin would not be necessary since plastic sheets are waterproof. For further stability, the final prototype should have anchors. Overall, for future projects, advanced research should be considered to find materials to improve the quality of the shelter design.

Conclusion

There are diverse migratory populations that are in need of temporary shelter. After investigating the range of requirements of these stakeholders, we have been able to find many design innovations that can be implemented into a shelter that could satisfy their needs. Moving forward, these shelters could have merit with other stakeholder groups as well. Further research could evaluate their effectiveness as relief or refugee housing, for example, given the ease of transport of these shelters to affected areas.

Moreover, we have discovered that origami can contribute greatly to engineering applications and has far more capabilities than what we imagined in the beginning. Thus, we can conclude that the art of folding can transform the way structural problems are solved. We hope that this application of origami will not only positively contribute to any group that requires a temporary portable shelter, but to the engineering communities as well.

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Supplemental Materials: Methods

Interview Questions

1. How many people live in your shelter? (Size)

2. How did you make your shelter? (Traditional methods/Materials)

3. How do you find your land? (Terrain)

4. How often do you move? (Travel Frequency)

5. What are some features that you like about your shelter? (Design Spec.)

6. What are some features that you dislike about it? (Design Spec.)

7. What do you find necessary to have a good shelter? (Design Spec.- Materials, Insulation, etc.)

8. How much are you willing to carry? (Design Spec. -Weight)

9. What is the land that you normally live on like? Please describe. (Terrain, Location)

10. If a light and portable shelter was designed and made accessible to you, would you be interested on having one? (Interest)

11. What is your average income? (Financial)

12. What is the weather like where you reside? (Weather)

Supplemental Materials: Results

Interview Questions	*Groups* / ***Location/Date***	**Group 1 (CW:3 people)** North Campus(3/24/15)	**Group 2 (CW: 2 people)** North Campus(3/24/15)	**Individual 1: CW** North Campus(3/24/15)	**Individual 2: CW** IIT-Kamand(3/25/15)
How often do you move	< a month				
	1-3 months				
	3-6 months				6 months
	> 6 months	2-3 years	2 years	1 year	
Features that you like/dislike about your shelter?	Like	N/A	N/A	Electricity	Better insulation during the day, protection from rain
	Dislike	No insulation, no protection from the rain	No insulation, no protection from the rain	Sometimes gusty winds destroy house	N/A
How many people live in your shelter?	1			x	
	2			x	
	3				
	4	x	x		x
	5	x	x		
	6				
	7				
	8				
How did you make your shelter?	Materials	Tin sheets, wooden frame structure	Tin sheets, wooden frame structure	Tin sheets, wooden frame structure	Bricks and Tin sheets(with wooden frame structure)
What do you find necessary to have in a good shelter?	Comments	Insulation, ventilation, big enough, decorative	Insulation, ventilation	Insulation, ventilation	Insulation, ventilation
How much are you willing to carry?	Comments	Any amount possible	25-30 kg	Any amount possible	20-25 kg
What is the land that you live on like?	Terrain	Usually mountainous	Cities(flat terrain)	Mountainous	Mountainous
If a light and portable shelter was designed and made accessible to you	Yes	x	x	x	x
	No				
How much can you afford for the shelter?	Comments	1000-1200 Rupees	500-1000 Rupees	5,000- 20,000 Rupees	500 Rupees
What is the weather like where you reside?	Comments	Rainy, windy winters and hot summer	N/A	Rainy, windy winters and hot summer	Rainy, windy winters and hot summer

Interview Questions	Groups	Group 5: Slum People: 2 people	Group 6: Homeless people: 3 people (3/29/15)	Individual 3: Gaddi Herder	Individual 4: Trekker	Individual : Gaddi Herder (Near Badi Court)	Individual: Expert trekker	Group trekkers: 2 people
	Location/Date	Mandi Slum Neighbor hood (3/28/15)	Mandi-Tibetan Market	IIT's Road (4/8/15)	Kamrunag	IIT's Road (4/8/15)		
How often do you move	< a month	Once a month (moves for work when needed)	Everyday	Every 2-3 nights	daily while treking	Every 2-3 nights		
	1-3 months							
	3-6 months							
	> 6 months							
Features that you like/dislike about your shelter?	Like	None	None			None		
	Dislike	Materials used, don't own land, weather	No roof, uncertainty, no protection from anything			Unstable, Difficult to set up, doesnot provide complete protection in		mosquitoes
How many people live in your shelter?	1				x		x	
	2						x	
	3					x		
	4		x (in one shop)	x				
	5			x				
	6	x		x				
	7							
	8						x	
How did you make your shelter?	Materials	Plastic sheets, wood, and scrap materials	Public places	From clothes		Plastic sheets and jungle wood	owns tent	
What do you find necessary to have in a good shelter?	Comments	More room, stability	Roof, must be warm	Waterproof, ventilation	tall enough to sit in, floor, waterproof, size(6x3 ft)	Waterproof, easy to set up	waterproof, sealed, ventilation, anchored	waterproof, floor, anchored
How much are you willing to carry?	Comments	<15kg	N/A		5kg	5-10 kg	<5kg	
What is the land that you live on like?	Terrain	Cities	Cities	Mountainous	Mountainous	Mountainous	Mountainous	near river
If a light and portable shelter was designed and made accessible to you	Yes	x	x		x		x	
	No							
How much can you afford for the shelter?	Comments	N/A	0	3000-4000 rupees		less than 1000 rupees	3,000-5,000	
What is the weather like where you reside?	Comments	Cold, rainy and warm summers	Cold, rainy and warm summers			Depends upon season, Rain and wind is common	Summer, rain and wind	

Supplemental Materials: Prototype

The prototype was constructed from a circle 167.5cm in radius. The circle was then divided into 16 equal slices. One of these slices before folding is seen below in Figure 17.

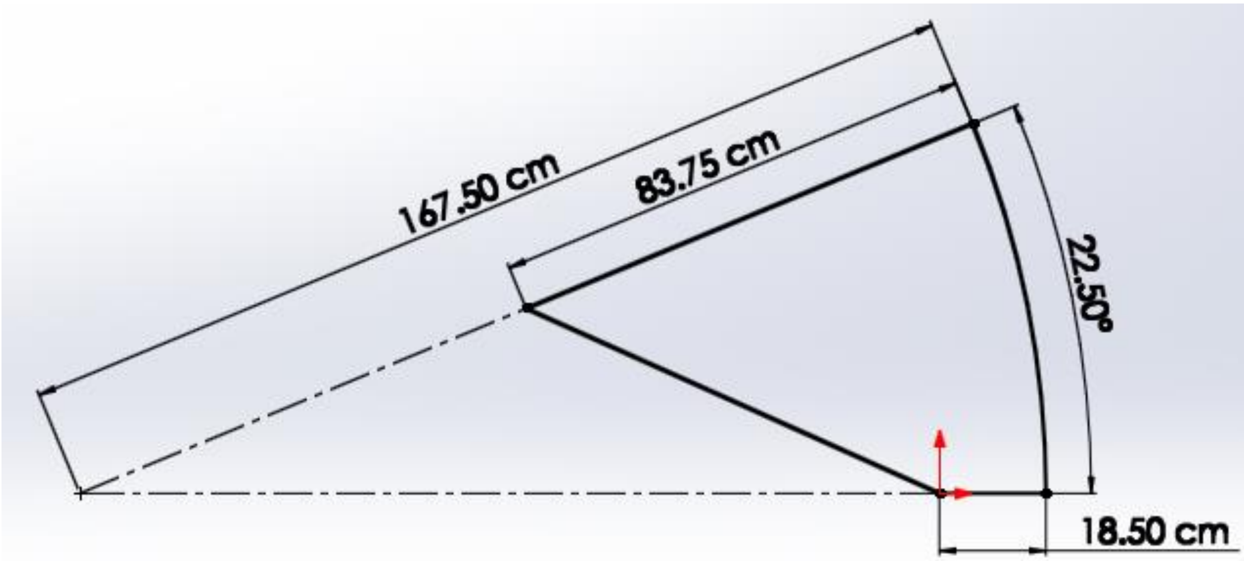

Figure 17. Before folding

Once the slice was folded the dimensions were as seen below in Figure 18. Once folded the 16 slices were secured together to make the full prototype.

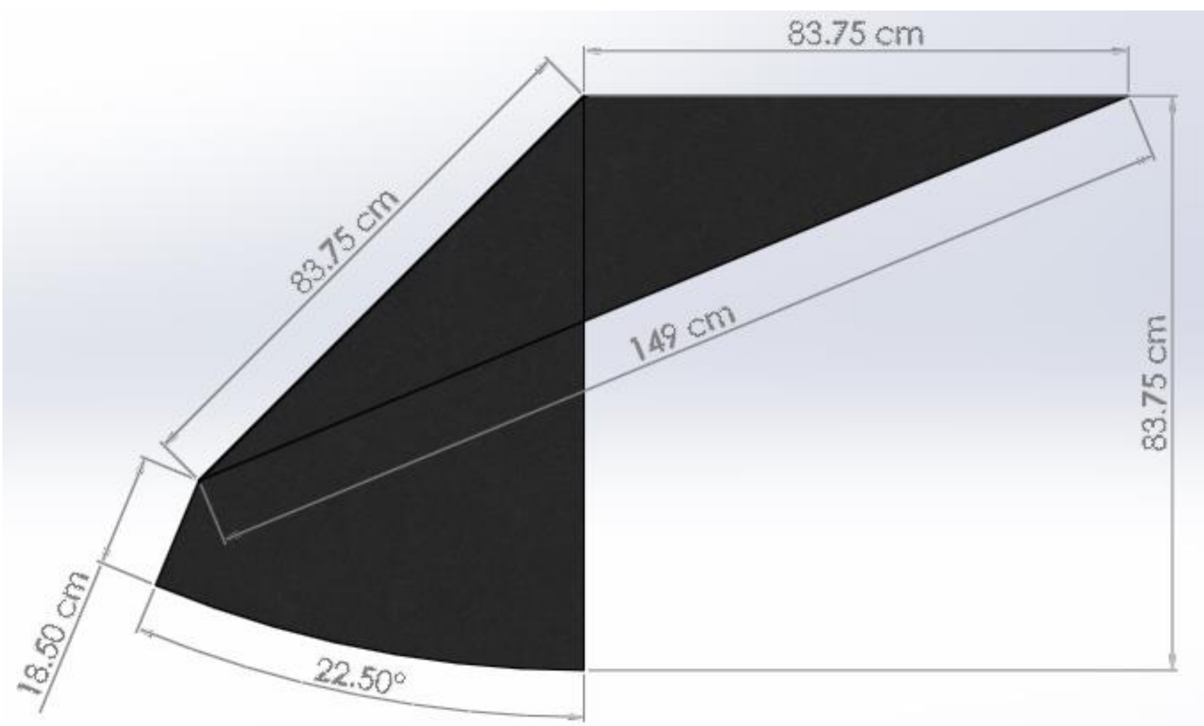

Figure 18. After folding.