Disaster-Resilient Housing—Sustainable Cities and Communities

This project is inspired by Habitat III (http://habitat3.org), the United Nations' (2017) initiative for sustainable urban development. Out of 7.5 billion people in the world, more than one billion—or one in ten people, live on less than $1.90 a day (The World Bank, 2019a). Cities are home to 55 percent of the world's population, urban areas are the engines of global growth contributing to 80 percent of global GDP (The World Bank, 2019b). However, the high density of people, jobs, and assets that make cities successful also makes them, and global industry, extremely vulnerable to the wide range of natural shocks and stresses.

When natural disasters strike, they often affect the most vulnerable people; this is particularly true in the developing world. This project focuses on designing and building housing that is resistant to natural disasters common in these vulnerable communities, both urban and rural.

Our essential questions follow.

- How can we design and build a disaster-resilient housing system with appropriate technology in the region of interest?
- How can we implement this housing into the local communities?
- How do we create awareness about the product so it is more accessible?

Sustainable Development Goals

The UN's (n.d.) sustainable development goals (SDGs) will mobilize worldwide efforts to end all forms of poverty, fight inequalities, and tackle climate change, while ensuring that no one is left behind. The new SDGs call for action by all countries—poor, rich, and middle income—to promote prosperity while protecting the planet.

This project focuses on SDGs 11—Sustainable Cities and Communities, and 15—Life on Land (UN, n.d.). Using the SDGs as the center point of this project allows students to focus on three things: (1) developing awareness of global challenges and conditions, (2) understanding the ethical and cultural issues involved in appropriate technology development, and (3) using the engineering design process (EDP).

Ending poverty requires a strong commitment to reducing disaster risks. Otherwise, development efforts for the poorest will be unsustainable. Without better infrastructure and management, millions of people will die every year, and there will be further losses in biodiversity and ecosystem resilience, undermining prosperity and efforts toward a more sustainable future.

Project Summary

This design challenge asks students to design and build a prototype of a disaster-resilient housing system made from various materials. This design challenge encourages and rewards excellence in design that integrates the following, in addition to being fun.

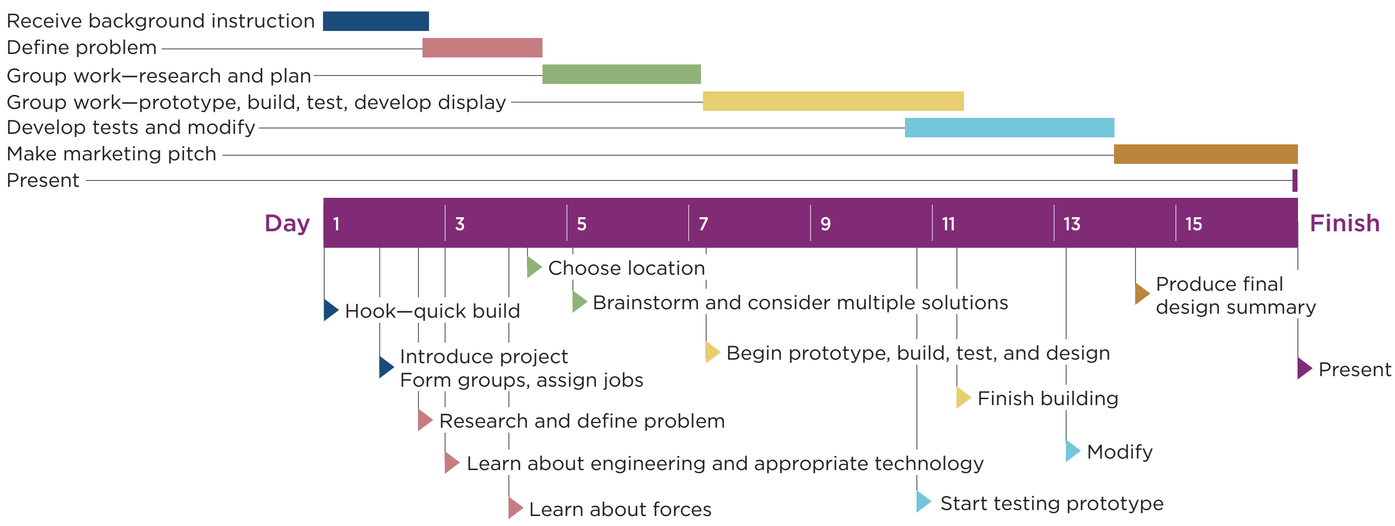
- **Function:** Does it work?
- **Aesthetics:** Does it please the eye?
- **Ergonomics:** Is it comfortable for the average family in this region?
- **Details:** Are the drawings and actual construction accurate?

Working in design teams students complete extensive research to identify the needs of their client and identify the key concepts needed to design and build. They learn the physics underlying the design and build, as well as the materials needed to build housing. Students get an opportunity to learn about core physics content, forces acting on a structure, Bernoulli's principle of fluid behavior, and use this knowledge to build better communities in developing regions (National Aeronautics and Space Administration, n.d.).

Project Timeline

This is the proposed project timeline.

Project Management Timeline



Next Generation Science Standards

The Next Generation Science Standards (NGSS Lead States, 2013) were developed around three major dimensions: (1) scientific and engineering practices (SEPs), (2) crosscutting concepts (CCCs), and (3) disciplinary core ideas (DCIs). These three dimensions are the key components of the NGSS, and this project connects to all three.

The DCIs are science and engineering concepts that have broad importance within and across disciplines as well as relevance in peoples' lives. Connections to the DCIs appear in the following table by connecting content to specific scientific disciplines. It is important to note that each DCI has a collection of performance expectations on the NGSS website (https://bit.ly/2jWNZiO).

The following table boldfaces the SEPs and the CCCs that students will develop a deeper understanding of while working on the Disaster-Resilient Housing project.

Science and Engineering Practices	Crosscutting Concepts
1. Asking Questions and Defining Problems	1. Patterns
2. Developing and Using Models	2. Cause and Effect
3. Planning and Carrying Out Investigations	**3. Scale, Proportion, and Quantity**
4. Analyzing and Interpreting Data	4. Systems and System Models
5. Using Mathematics and Computational Thinking	5. Energy and Matter
6. Constructing Explanations and Designing Solutions	**6. Structure and Function**
7. Engaging in Argument From Evidence	**7. Stability and Change**
8. Obtaining, Evaluating, and Communicating Information	

Source for standard: NGSS Lead States, 2013.

Disciplinary Core Ideas

NGSS Lead States (2013) supports the DCIs.

MS-PS1.A: Structure and Properties of Matter

- "Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms." (MS-PS1-1)
- "Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals)" (MS-PS1-1)

PS1.C: Structure and Properties of Matter

- "The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms." (MS-PS1-3)

PS2.A: Forces and Motion

- "The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion." (MS-PS2-2)
- "For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first but in the opposite direction (Newton's third law)" (MS-PS2-1)

- "Gravitational forces are always attractive. There is a gravitational force between any two masses, but it is very small except when one or both of the objects have large mass –for example, Earth and the sun." (MS-PS2-4)

MS-ETS1-1 Engineering Design: "Define the criteria and constraints of a design problem."

- ETS1.A: Defining and Delimiting an Engineering Problem
    - "The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions."

MS-ETS1-2 Engineering Design: "Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem."

- ETS1.B: Developing Possible Solutions
    - "There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem."

MS-ETS1-3 Engineering Design: "Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success."

- ETS1.C: Optimizing the Design Solution
    - "Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process – that is, some of those characteristics may be incorporated into the new design."

MS-ETS1-4 Engineering Design: "Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved."

Learning Goals

Learning goals follow.

Key Content

Here is the key content.

- Understand structures and the forces in a housing system
- Identify how different weather conditions apply different types of forces
- Identify issues climate pose to vulnerable regions
- Understand the cultural influences on local architecture and design
- Identify appropriate materials to the region

Skills

These are the skills students work on during this project.

- Implement and identify key steps in the design process in order to develop creative, effective designs through concept creation, problem formulations, application of other competencies, balancing tradeoffs, and craftsmanship that are influenced by physics concepts to solve real world problems
- Organize building, testing, and modification based on physics principles
- Design solutions need support through research to meet the needs of the end user and the design problem

- Work on tasks with their team and individually, taking advantage of individual strengths, identifying areas of improvement, and learning from their peers
- Understand how using appropriate technology and materials can lead to more sustainable design solutions
- Engineer and apply technology to meet the challenges of the future
- Use and develop appropriate collaborative and interpersonal skills to teach and encourage each other to learn.

Sequence and Instructional Tools: Detailed Project Plan

The plan is split into days.

Day One

Get your project started with a hook. To prime students for designing and developing a prototype housing system for specific real-world communities, view the following series of TED Talks. It is important *not* to address the project at this point. Instead, inform students that they will consider a good example of how they might solve problems in the real world. With students, discuss what the design process in the videos looks like, and if it was different from what they expected in the real world.

Use videos with direct connections to housing. The discussion questions are based on the first two. The last three videos are simply additional options.

- "When Bad Engineering Makes a Natural Disaster Even Worse" TED Talk by Peter Haas (2010; https://bit.ly/1xbNdvy)
- "Emergency Shelters Made From Paper" TED Talk by Shigeru Ban (2013; https://bit.ly/1Ty0Uj9)
- United Nations' (2015) "Sustainable Development Goals Explained—Communities and Resilience" (www.youtube.com/watch?v=-K-y83EDmtU)
- United Nations' (n.d.) "Introducing Disaster Risk Reduction and Resilience" (www.youtube.com/watch?v=iugLHrcs_fM)
- The Nature Conservancy's (2016) "Sustainable Cities: Nature-Based Solutions in Urban Design" (www.natureworkseverywhere.org/resources/sustainable-cities)

Ask the whole class the following questions and record answers on whiteboard or display, or have students work in pairs to facilitate the discussion.

- "What stands out about the housing projects in the videos we saw?"
- "What did the team accomplish with its designs?"
- "How did the design teams work empathically, or from the perspective of the people who needed help?"
- "How did the team consider the needs of the people involved?"
- "Why didn't the team just raise money to build a traditional unit for the people?"
- "How did the team thoughtfully define and consider the problems at hand?"

Day Two

Approach day two with a quick build based on the Paper Tower of Power activity, where students design a prototype paper tower with basic materials, then complete the "Figure 2.12: Project Summary and Reflection Form" reproducible.

Groups will only get twenty minutes to complete this task. The Paper Tower of Power is a quick build designed to get students thinking about design functionality and materials, and prototype this idea to visually representation it. Keep an eye on how students work with each other, so when groups start to form in the next few days you can identify and prepare to work with challenging groups. While testing the prototype, encourage students to carefully observe and record the process. Failure is going to happen. Support what the students can learn during this and if time permits, allow them to modify or use an additional material.

Ask students to discuss the following questions among themselves, and then with the whole class.

- "What are some natural disasters that affect the world, and why do they exist?"
- "Who is most affected by natural disasters. Consider countries, regions, and people."
- "What would your community do if it couldn't rely on the government for aid in local disasters?"

Days Three and Four

This is a good time to introduce the design challenge, break the class into design groups of four, and initiate job title decisions in each group. Remember how students worked together during the quick build or previous group activities as you choose group members. Give students time to identify each member's job and responsibility. Potential roles and responsibilities appear in the following table.

Jobs

Jobs for this project are in the following table.

Role	Responsibility	Research Task
Project manager	Stays organized and keeps track of paperwork and progress. Has final say in any tied decisions.	Researches common causes of failure, where the natural disaster tends to happen, and how many people can be impacted.
Geological scientist	Explains what the natural disaster is and why it happens.	Researches the science and cause behind tsunamis and extensive flooding, and the effects of moving fluids on structures.
Structural engineer or architect (Large groups can have both)	Develops ideas for the structure based on available materials and the region's local design preferences.	Researches current technology in flood-resistant housing. Gather information about recent floods and photos of housing in countries most often impacted.
Marketing manager	Responsible for designing company logo, vision, and name that best represents the product and the company. Coordinates final presentation and marketing pitch.	Researches potential regions or countries for which the group can design housing and what is important in that market.

Before students start research, facilitate a group and classroom discussion about the key ideas and understandings students will need to know. Give each group between five and ten minutes to identify the following.

- Three key academic concepts
- Three key understandings about location or geography

- Three key understandings about the housing system's end users

Then facilitate a discussion so that you have identified the project's major need-to-knows. Display this on chart paper or bulletin board throughout the length of the project.

Background Research

Allow some introductory research on regions of interest for design teams and end user identification. This will allow for a more aligned set of criteria and constraints. This may only take fifteen or thirty minutes; depth is not the concern.

You can easily assign design teams to read the articles in class or at home. During the following class day, give teams time to share their research information followed by a class discussion on important needs for the design.

- "To Curb Deaths From Disasters, End Poverty: U.N. Chief (Rowling, 2016; www.reuters.com/article/us-global-disaster-poverty-idUSKCN12D04O)
- "Sustainable and Eco-Friendly Disaster-Resilient Housing" (Fischer, 2015; www.builddirect.com/blog/sustainable-and-eco-friendly-disaster-proof-housing)
- "The Devastating Impact of Natural Disasters" (ChildFund International, 2013; www.childfund.org/Content/NewsDetail/2147489272)
- "Why Climate Change Is a Women's Issue" (Pearson, 2017; https://bit.ly/2kn1BUU)
- "Disaster Risk Reduction Must Take Account of People's Lives" (Soria, 2017; https://bit.ly/2IW68y8)

Design teams should consider the following as they focus their research and align criteria and constraints.

- What exactly is the disaster risk in the region of choice?
- Why is this the case? Is it structural, about materials or finances, or something else?
- What types of forces does this risk have?
- What do people in the community use the structure for—a house, business, or municipal building?
- What have people already tried as solutions?
- What materials can you work with?
- What is the area like physically?
- How do you test the house?

Days Five Through Seven

Here is when you make a content connection.

Lesson: Forces and Structures

Students are introduced to the five fundamental loads: compression, tension, shear, bending, and torsion. They learn about the different kinds of stress each force exerts on objects. Engineers take into consideration the impact of many types of forces when design decisions include anticipated use of the structure, expected weather exposure, and the type of soil it will be built on. Engineers choose the best materials and design approaches for buildings by calculating how much and what kind of stresses each material can withstand without failure.

Key Understandings

Here are important key understandings.

- The five fundamental loads: compression, tension, shear, bending, and torsion
- The influence and properties of materials in relation to forces

- Center of mass of a structure and its importance in keeping a structure upright through various types of forces
- Stability and change in the natural or designed systems and changes over time and forces at different scales

Key Concepts

These are the key concepts.

- Difference between natural hazards versus natural disasters
- Weather and climate patterns
- Cause-and-effect relationships of disasters on vulnerable regions of the world
- Importance of disaster prevention

Day Eight

Do an activity for identifying criteria and constraints. It should take one full class period (about forty-five minutes). Project managers will facilitate design teams through ranking criteria ("Figure 4.3: Criteria Ranking Activity Form" reproducible) and identifying constraints to identify importance of key design elements.

Day Nine

Design teams begin the brainstorming phase of generating ideas. The teacher encourages divergent thinking throughout this process and uses supportive language during discussions. At this point there is no bad idea—they all work. Design teams need to think past their constraints and criteria while brainstorming. The "Brainstorming Summary" reproducible facilitates this process.

Additional materials might include various color sticky notes and either large poster paper or a whiteboard (for writing ideas on).

Day Ten

Design teams, based on their criteria and constraints and brainstorming sessions, will use the "Initial Design Plan" reproducible to start planning their solution to the challenge. This takes between forty-five and ninety minutes.

The background research plays a big role in shaping their solution and the materials they use. It is important that the solution stay within their design space (defined by their criteria and constraints).

- Project managers facilitate this process with the help of all group members.
- Engineers sketch and prototype components of their disaster-resilient housing system, and list the materials to organize their solution.
- Marketing designs a company logo and name focused on the group's overall vision and solution.

This is the first time the team has identified their solution in a more formal way. Although pieces of the design will change throughout the process, this is a great opportunity to formatively assess them.

Days Eleven Through Fifteen

This is the building phase. Design groups have identified a solution, with a focus on how it's meeting end users' needs.

- Project managers work with the engineers in staying organized and criteria oriented.

- Engineers are primarily responsible for the build and materials to ensure they are meeting the functionality of their solution.
- Marketing works with the engineers for possible ways to test the product functionality and meeting the identified criteria and constraints.

Give students five minutes at the end of class for the groups to use the "Daily Summary" reproducible for reflection. This allows the group to discuss daily accomplishments, how they got them closer to completion, and a focus on next steps.

It is important for design teams to have identified the type of risk (wind, water, or both) they are facing. You can test and experiment with different types of models that fit the discipline you are teaching. It's OK if your teaching background is not science; students will dig into the content and engineering behind it to understand the *why*.

If you are supplying all materials, let students know what will be available. If they can supply some materials from home, place a reasonable limit and require teacher approval. If desired, groups can indicate what they have used.

Days Sixteen Through Eighteen

Design teams will test their structures based on a class set of testing stations.

- Wind—using a fan or blow dryer, changing the wind's direction
- Water—seeing if the house is buoyant, moving the water

Work with students to determine how many tests they need and acceptable levels of all variables. Based on the data and observations, how can the product be improved or modified to improve results?

If they want to make modifications, students should indicate what they are, the anticipated effect, and the actual results. Modifications should always be done one at a time to establish causality, and they should be limited to a total of three. Doing more results in a whole new design. The "Design Modification Request" reproducible mimics documentation found in industry. The project manager focuses on the "Final Design Summary" reproducible, which should be complete once all testing, modification, and feedback is finished.

Days Nineteen and Twenty

As a method of presenting their solution, design teams can also conduct a five-minute presentation to fellow students. The focus is to promote funding from outside government agencies to advance their product development. This is a great opportunity to make the project authentic and invite local builders, disaster-relief agencies, or nongovernmental organizations to class so students can make a marketing pitch presentation to "sell" them their design. This way, students receive and record real-world feedback from professionals in the field. The "Figure 2.14: Project Presentation Feedback Form" and "Figure 2.15: Pitch Feedback Form" reproducibles may be helpful here.

Note: You don't have to use all methods of assessing or presenting the final solution. They can test the product for technical aspects and prepare a report instead of pitching. Test marketing and pitching are optional techniques for innovative communication and assessment.

For assessment, each student's grade is comprised of 30 percent individual performance and 70 percent design team performance. Focus assessment on the engineering design process as well as the depth of understanding of the science and mathematics involved in the design. If cultural issues were stressed, they should be part of the assessment.

Materials

These are the materials

Project-specific materials:

- Newspaper
- Tennis balls
- Corrugated cardboard
- Empty plastic bottles
- Fabric scraps
- Wire or string
- Foam shapes
- Card stock
- Floral foam
- Mesh or screening
- Foam sheets
- Bosal wood scraps
- Duct tape
- Any scrap materials that c*ould add to building the structure.*

General engineering supplies:

- Paper clips
- Pipe cleaners
- Rubber bands
- Push pins
- Binder clips
- Aluminum foil
- Plastic wrap
- Straws
- Various types of tape
- Foam core (limit to 25 to 30% use on house's surface area)
- Hot glue guns and sticks
- Utility knives
- Scissors

- "Sustainable and Eco-Friendly Disaster-Resilient Housing" (Fischer, 2015; www.builddirect.com/blog/sustainable-and-eco-friendly-disaster-proof-housing)
- "The Devastating Impact of Natural Disasters" (ChildFund International, 2013; www.childfund.org/Content/NewsDetail/2147489272)
- "Why Climate Change Is a Women's Issue" (Pearson, 2017; https://bit.ly/2kn1BUU)
- "Disaster Risk Reduction Must Take Account of People's Lives" (Soria, 2017; https://bit.ly/2IW68y8)

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