

(RE)Covering Shelter: Enhancing Structural Design Pedagogy by Designing for Disaster Relief

The pedagogical model for teaching structural design to architecture students can be enhanced with the inclusion of design-based exercises that are purposefully constrained by programmatically justifiable and technically specific limits, like those found in design of disaster relief shelters.

URGENT CONDITIONS & EXPANDED OPPORTUNITIES

Thirty million people on average are displaced each year by natural disasters resulting in an acute worldwide demand for effective relief shelters.¹ These prolific and persistent humanitarian crises pose a myriad of daunting operational and design challenges, particularly the need to immediately shelter a significant number of people in diverse locations using relatively limited resources. As a result of these constrained conditions, these structures must be designed with an elevated level of purposefulness and efficiency.

Relief operations rely heavily upon the availability and usefulness of shelters, expecting more from the design than just basic protection.² Specifically, shelters must strive to be: structurally efficient yet strong, durable and secure; efficiently fabricated, packaged, and transported to remain affordable and accessible; easily assembled and disassembled by a non-traditional workforce under difficult site conditions; and accommodating to a variety of uses and operations.

Unfortunately, many of these convergent programmatic goals may be in relative opposition to each other (e.g., an affordable shelter may not be very durable, an efficient structure may not be easily assembled, etc.). In order to determine the relative importance of each seemingly paradoxical factor, a technically rigorous and comprehensively considered reiterative design process must be undertaken. These unique project considerations present both significant challenges and compelling educational opportunities.

Functional and technological factors, including many that fall outside the typical scope of an architectural education, need to be considered side-by-side using both qualitative and quantitative in order to improve the design.

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Figure 1: After constructing the models, students try to predict its behavior under loading through haptic learning exercises (including pushing and pulling on the model). They discuss their predictions and results within an active learning environment.

Regrettably, traditional pedagogical models separate technology courses from design exercises, unnecessarily denying this important educational opportunity to students; technical rigor should be used to enhance design exploration and evaluation. This paper will argue that the pedagogical model for teaching structural design to architecture students can be enhanced with the inclusion of design-based exercises that are purposefully constrained by programmatically justifiable and technically specific limits, like those found in design of disaster relief shelters.

The undergraduate structural design sequence for architecture students at Iowa State University has recently been dramatically reconfigured to include regularly occurring design exercises in an active-learning lab environment—this paper will document one of those labs, a week-long research and design exercises focused on disaster relief shelters. Key aspects of this course’s non-traditional pedagogical organization and procedures will be briefly outlined in order to demonstrate how this particular lab’s designated learning objectives fit within this broader frame of reference. A description of the lab’s assignment will be presented along with an abbreviated summary and analysis of student work, a description of assessment methods and conclusions.

RE-STRUCTURED SEQUENCE

In order to better prepare architecture students for the importance of considering structural technologies as a central design consideration, structural design pedagogy must evolve. Traditionally, architecture students have been taught using an engineering-based system of abstract analysis and representation in which the scope of “design” is confined to the analysis and sizing of elements, and assessment is based primarily on the accuracy of these calculations. This capacity to quantitatively assess a design is useful in situations where the scope of work is already established, but designers are commonly faced with problems that involve a more holistic evaluation of inter-related design options, like those found in the design of disaster relief shelters. Presenting this type of information primarily through a passive learning environment, like lectures, favors a particular learning style (sensing) that is frequently mismatched with the preferred learning style of the plurality of architectural students (intuitive). A combination of these factors can adversely affect the effectiveness of the learning.³

To address these deficiencies, major revisions were made to the traditional pedagogical model for teaching structural design to undergraduate architectural students at Iowa State University. This sequential multi-semester lecture and lab course module, titled Structural Technology in Practice (STP) incorporates a series of purposefully selected, structural-centric, design exercises into the coursework. A large portion of the work takes place in an active-learning lab environment, more akin to a design studio, in which students are taught to develop different strategies for creating assessing their work—including many haptic learning opportunities (Figure 1). The process is known to the students simply as “think, make, break, + evaluate.”⁴

Students create laboratory reports that include descriptions of their designs alongside technical diagrams, calculations (when required), and a summary of “lessons learned” about the topic. This approach helps broaden the options for learning styles and promotes a multimodal means

of representations—both demonstrated strategies for increasing the learning capacity, retention and enthusiasm.⁵ Through the research, design, and evaluation stages of the process, students realize that relative success of their design interventions are inextricably linked with their realistic engagement with a broad range of technical encumbrances not normally required of them in studio.

LAB ARRANGEMENT AND PREPARATION

Interactive learning environments are typically more effective with a smaller group of participants, and so this course's 80 students are equally divided into five smaller "studio-like" sections, each led by a teaching assistant. Most assignments typically require students form smaller teams—in this case, teams of 6-8 people were formed.

Because this assignment occurs near the end of their overall structural design sequence (the 40th of 45 total labs), a certain level of knowledge about member sizing (including rule of thumb estimates), strategies for creating stable framing arrangements, material performance standards, behavior of different structural connections, and various options for framing arrangements had already been explored in some detail. This general aptitude was an important precursor to the success of the lab because the technical challenges inherent in the design of disaster relief shelters are so comprehensive. The previous two assignments had also dealt with small-scale structures that used off-site/prefabricated components, so this assignment was more of an extension of previous lessons.

The assignment's deadline, one week, was ambitious. Both lectures that week presented relevant information about the topic alongside real-world examples. The labs were set aside as dedicated work time for the teams so that ample opportunity for interactions with instructors was available.

ASSIGNMENT OBJECTIVES AND ORGANIZATION

The assignment's specific objective was to have design teams to apply their knowledge of structural design principles (including materials, component sizing, arrangement, assembly, and overall functional performance) towards the research/analysis and schematic design of an efficient and effective emergency relief shelter.

The assignment was inspired by the real world efforts of the United Nations relief Agency, United Nations High Commissioner for Refugees (UNHCR), the United Nations Office for Disaster Risk Reduction (UNISDR), the Disaster Assistance Program at the American Institute of Architects (AIA) Center for Communities by Design, and a consortium of non-profit relief foundations (Red Cross, World Vision, Habitat for Humanity, etc.) that are currently working with private companies to develop better design alternatives for shelters.

A consolidated set of design considerations was collected from these resources and presented to students in the assignment. Their work needed to address the following inter-related facets: fabrication, packaging/deployment, means of assembly, cost/availability, durability, security, and re-usability/sustainability.



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In the first part of the lab, teams were required to research, discuss, and document at least two different types of emergency shelters that they found interesting, effective, and/or engaging. They were asked to develop an explanatory summary and a brief graphic analysis of what they learned about how the particular shelter worked functionally and structurally. Specifically they were required to analyze the relationship between the shelter's structural system, its means of enclosure, and the process of its deployment (Figure 2).

The effectiveness of the precedent research was somewhat limited by the availability of detailed technical information available—online examples typically avoided this information (perhaps for proprietary reasons) in lieu of more “marketable” information about the benefits of its use and cost. When faced with limited available information, students were asked to make educated guesses about the structural materials, size of components, and overall structural design strategy. These limitations created an unanticipated but beneficial learning opportunity. When students are asked to speculate about potential physical behaviors (i.e., how a structure works) by representing this behavior (through drawings or other simulations), it has been shown to be more effective than having them simply look at completed visual imagery alone.⁶

In the course of their research, students came to realize that shelter designs were frequently represented using similar means. Specifically, they primarily used three-dimensional representations of space (i.e., rendered computer models), represented the process of transportation, erection, and occupation as a series of drawings (including the incorporation of human scale figures), and showed the various options for shelter accessories and arrangements (as a kit of parts).⁷ Because there is often an importance placed on the efficiency of construction assembly, most drawings featured information on the respective connections between elements alongside data about the shelter's overall weight.

Figure 2: An example of the information collected by students that were studying the ModularFlex system; besides representing the final form, it also includes information on shipping, assembly, and connections.

DEFINING THE DESIGN

The second phase of work involved the design, or alternatively the redesign, of a disaster relief shelter. Students were encouraged to incorporate

information from their research to better refine the scope of their new design work. They were allowed to change and improve an existing construction system used for shelters, improve an existing system of delivery and/or deployment, or otherwise improve a shelter's geometry, form, or structural configuration in an effort to improve efficiency or performance.

Design teams weren't asked to calculate the size of the structural members (most structures would be too complicated for even the most advanced coursework to accurately calculate) or mathematically analyze their relative stresses. Alternatively they were required to articulate, represent, and defend the proposed sizing of their structural members in their lab report. The idea was to simulate a professional design environment in which designers would be expected to make reasonable assumptions about component sizing and arrangements based on past experience, relevant research of similar precedents, and/or rule of thumb guidelines.

A set of three-dimensional drawings, similar in scope to what they uncovered in their research, was required. Specifically they were required to create a set of drawings that represented their project scope (i.e., volume, scale, materials, etc.) along side an "instruction manual" that demonstrates information about the intended process for fabricating, packaging/shipping, and/or deploying their shelter—a minimum of two stages of development needed to be shown.

EMBRACING CONSTRAINTS

There were several key design constraints put in place for the assignment in order to better direct the student activity towards the desired structural design learning criteria, to better consolidate the standards for evaluation and assessment, and to fairly match the assignment scope to the time constraints of the assignment. These conditions also corresponded with commonly accepted design criteria.⁸

First, these shelters were required to be free standing shelters that would be fabricated off-site, shipped to the location, assembled on-site, demounted and relocated for future use as necessary. They would be used during the recovery and reconstruction phases so they needed to accommodate long-term occupation (i.e., months at a time). Fabric structures, including both masted and pneumatic systems, weren't allowed for programmatic and educational reasons. Fabric structures aren't typically durable enough (they are typically only intended for short term use in emergency situations), they are notoriously difficult to analyze structurally, and they had been a specific topic of a previous lab these students had already completed.

Second, students were reminded that available resources to build, ship, and erect shelters are typically very limited so they were challenged to create highly efficient structural solutions that optimized resources—in doing so, students were directed towards solutions that pushed them to consider ways to make structures smaller, lighter, and more efficient in performance.

Of course, this particular constraint is a common design criterion for most structural assignments, but because the shelter design typically deals with additional programmatic constraints of shipping, erection, and limited component sizing, any unnecessary inefficiencies are more easily recognizable because they have more tangible consequences. This became the primary consideration for most of the resulting work.

RELATIVE ACCORDANCE

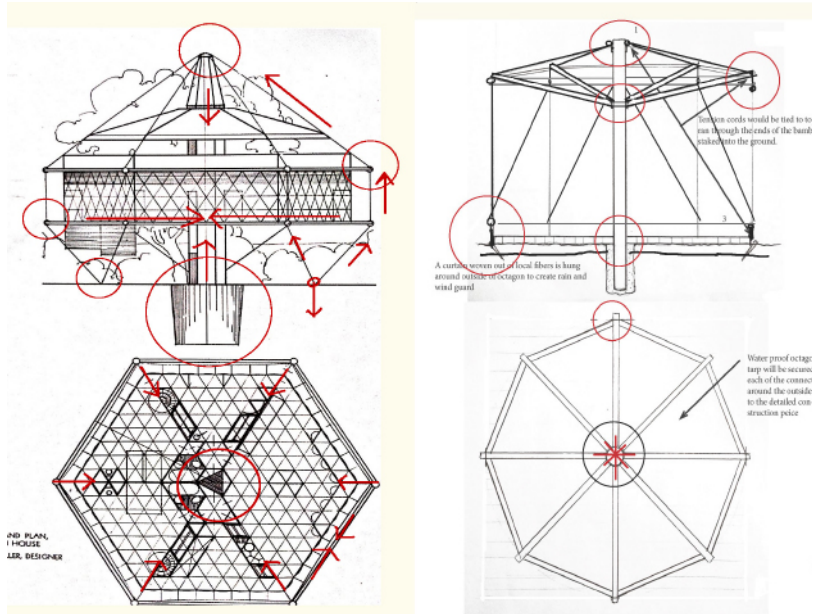
Because three major design considerations for shelters are all greatly influenced by a shelter's weight (deployment, assembly, and cost), many students assumed that lighter structures would be always preferable because they could be more easily transported, erected, and purchased. Most teams began the design process by developing options for idealized lightweight and structurally efficient structures—a common subject matter presented throughout the course. However, design teams found that lighter wasn't always better and that efficiency was a relative term when considering other design factors, such as durability, security, and reusability.

The first common design strategy was to create a lightweight “frame and skin” system for the shelter by using repeated modules of smaller than normal sized components that could be compactly transported and easily erected. A common tactic involved the use of small, segmented, tent-like hollow tube framing components that could be extended or snapped together to form a larger structural frame. Like tents, however, these systems were typically limited in span because of the smaller component size. To achieve a larger span, one team proposed that Konrad Wachsmann-inspired modular space frame could be used—an interesting advancement on the commonly used unfolding articulated truss system. Ultimately, teams discovered that smaller components meant more connections, which created more on-site assembly time (and potential complexity) and more opportunities for compromises in the durability of the components to occur.

Another way to create highly efficient structural forms involves the creation of forms that match geometry with statical function—a common STP topic.¹⁰ Three different teams proposed designs that enclosed the maximum amount of space using only minimal resources. The first team used form-active structural design-principles (employing only axially stresses components) in their proposal that mimicked Buckminster Fuller's original Dymaxion House proposal.¹¹ It featured a single centralized column and a series of cable supported elements radiating outwards to support the walls and floor—as with Fuller's proposal, many of the inherent efficiencies of structural performance, material use, and shipping are diminished by the inherent complexity of assembly (Figure 3).

The second proposal, inspired by the Exo Shelter by Reaction Housing systems, relied upon surface-active structural design principles.¹² The team argued that advanced manufacturing processes could be used to repeatedly cast prefabricated structural shell forms. These lightweight forms could be stacked together, like coffee cups, and efficiently shipped to the site. The validity of the idea has already been proven to work well, but the design team was surprised to learn that this structure (like nearly all prefabricated structures) would need to be sized based on the stresses induced during transportation and assembly, and not the in-situ gravitational or lateral forces anticipated.

The third proposal was inspired by a design-build prototype that was being constructed just outside their classroom by graduate students under my instruction. This group suggested that thin-shell structures could be created by adjoining a series of specifically configured smaller components—each component would be lightweight and flat, but when combined it would make an anticlastic form that could conceivably enclose a large space (for



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treatment areas or operational activities). These components could be parametrically modeled, rapidly fabricated, effectively shipped, and assembled on site. Although the proposal had great promise, limitations of time and expertise adversely affected their work and they struggled to advance the proposal past the idea stage.

PRACTICAL PANELS

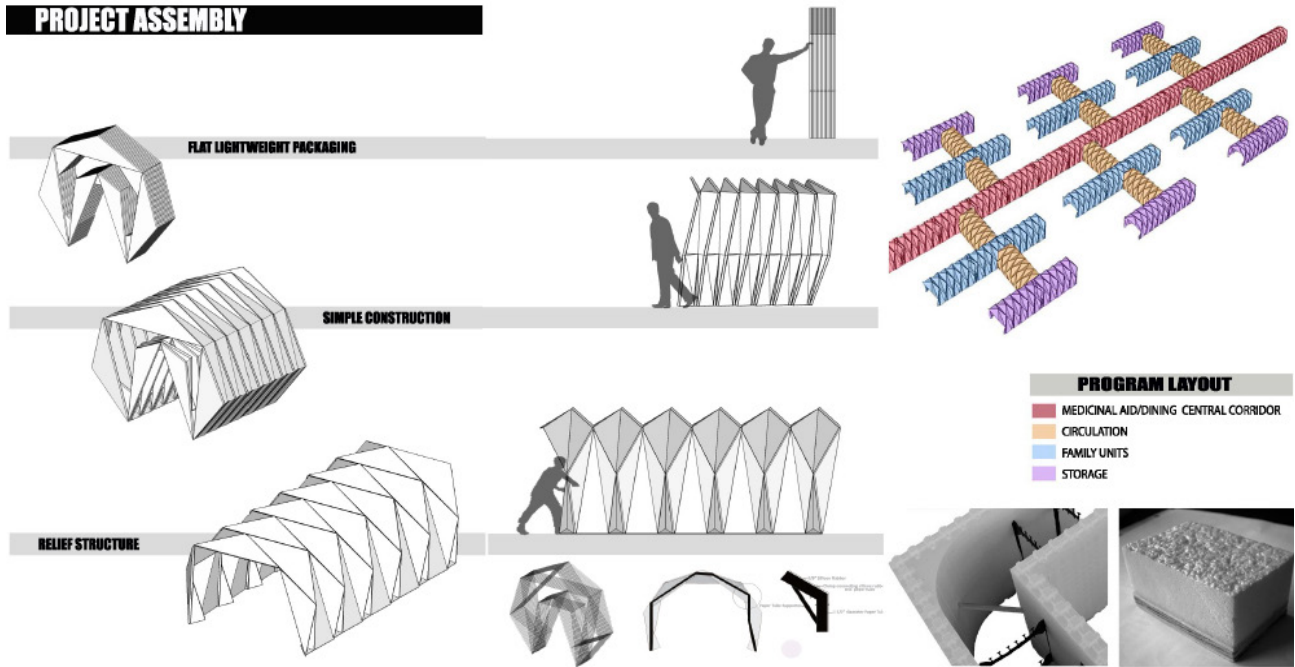
The most common strategy proposed by students was the use of flat-pack panel components. There are well-documented and tested efficiencies to be found in the fabrication, shipping, deployment, and security aspects of the structure. They can also be considered relatively efficient structurally, because unlike a typical post and frame structural system that specifically designates different structural performance goals to different components (load bearing versus stabilizing elements) these flat-pack panels perform multiple tasks (e.g., rigid wall panels support loads, provide lateral stability, and maintain security through enclosure). Flat-pack panels are commonly made from the same sized module that allows them to be efficiently built and stacked—it also means they can be interchangeable and customizable. As a result each panel thickness is sized the same structurally, regardless of its location, loads, or stress levels and floor and roof spans are frequently limited.

Many of the proposals and precedents, including a recently revealed IKEA-designed shelter, were relatively conventional and therefore somewhat uninformative in purely structure terms, but there were a few notable exceptions. One panel system, developed by ZipFlat systems is assembled in place by pouring an expanding polyurethane foam insulation between the interior and exterior panels—structurally this insulation gives the shelter its rigidity and load bearing capacity. One group proposed a useful modification; instead of relying upon flat panels to create a structurally inefficient box, they proposed that the panels could be reconfigured into a folded plate structure.

In their proposal, the interior and exterior panels would be precisely cut to the proper geometric configuration, adjoined together, and folded flat for shipping.

Figure 3: A comparison of Fuller's Dymaxion House and the student proposal for a similar shelter; image includes diagrammatic analysis of the structural forces and identification of key connection points.

PROJECT ASSEMBLY



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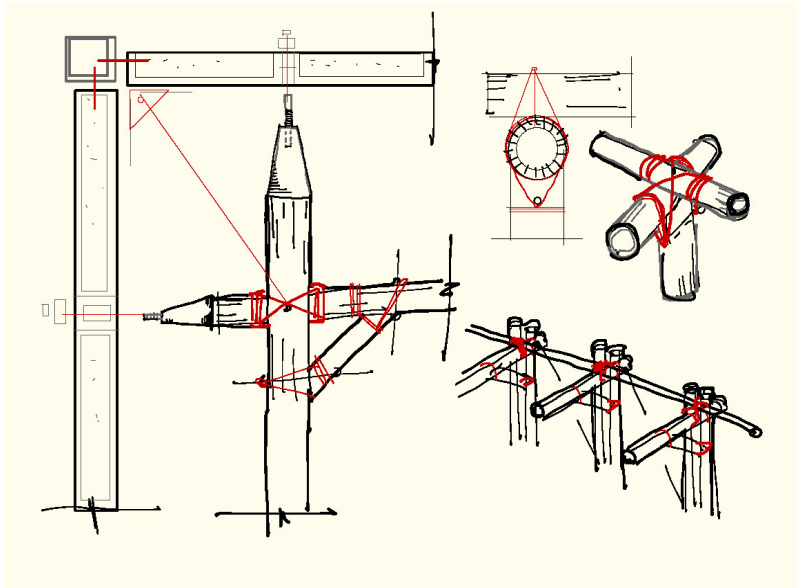
On site, the panels would be tilted into place, and with the help of a flexible hinging system, the entire shelter could be extended outward, like an accordion, until the correct configuration was achieved (Figure 4). Expanding foam would be cast between the panels to give it rigidity and to insulate it. There would be major impediments to making this system viable, but this level of creative engagement in these important technical issues unveiled a truly creative design option. making this system viable, but this level of creative engagement in these important technical issues unveiled a truly creative design option.

COMMON CONCLUSIONS

In general, these constraints led to a magnified focus on the materials of the components and behavior of various structural connections. Many proposals were concerned with selecting a material that was both lightweight and durable but they found that certain durable materials with an efficient strength to weight ratio (such as aluminum, fiberglass and carbon fiber) were frequently expensive and required more complex fabrication process. They struggled to defend the common discrepancies between durability and sustainability as well—a bamboo structure may be sustainable materially, but it may need to be replaced after each use.

In order to more easily assembly and disassemble the structural components, hinged and pinned connections were commonly deployed—students had learned that this requires an additional set of structural components to stabilize the structure from lateral deflection. Alternatively, some schemes used quasi-moment connections for their frames (the connections wouldn't be properly rigid) or simply relied upon panels to act as structural diaphragms. Panelized schemes needed to address the implications of whether or not their roof, wall, and floor joints were aligned or staggered. One group's work focused exclusively the connections between a somewhat traditional bamboo framing system and a more contemporary enclosure system made of insulated panels (Figure 5).

Figure 4: A design proposal for the accordion-like folded plate structure. This group included a proposal for how their shelter could be conjoined with others in a community setting, unfortunately they realized that the geometry of the folded plated structure was an impediment.



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ASSESSMENT AND EVALUATION

Although the assignment articulated several specific tasks that were required to be completed by each team and spelled out the criteria by which each topic would be evaluated, this particular lab created more problems for equitable standards of assessment than nearly any other previous labs. This is partially attributable to the nature of the assignment itself; this scope of work was more akin to the work typically completed in a design studio (albeit with an elevated expectation of technical acumen) and so the evaluative standards of certain aspects of this work is necessarily subjective. Teams were graded on the quality and clarity of their graphic work in both phases of the assignment but not too critically—primarily this evaluation was based on the completeness of information presented.

The design phase was more difficult—because each team was allowed to define the scope of their work, there was a big difference in the amount of work that was completed. Some teams completed new designs from scratch with marginal amounts of technical data included in their work while others opted for a more limited exploration (e.g., revising connection details of an existing structure) so they could provide a greater level of technical resolution. Each solution needed to be evaluated against the particular standards each team had established for itself, which unnecessarily complicated grading.

The second factor that adversely affected grading was the somewhat unrealistic expectations for the amount (and quality) of new design work that was required to be completed over such a compressed schedule. Even though previous assignments had dealt with similar structural design topics, the unique set of performance standards for disaster relief shelter design seemed to complicate progress.

Assessment is also frequently complicated by teams, particularly with the somewhat larger teams used for this assignment. Different levels of participation are to be expected, but if the assignment doesn't offer a variety of tasks, a disparity of participation can occur that would affect grading. This group size was intentionally made larger to ease the burden of work, but unintentionally, this led to many groups splitting up into two sub-teams

Figure 5: A working sketch developed in class that explored ways to combine bamboo connections (using dowels and lashing) with metal end fittings and threaded rods to connect the panel joints to the framing.

and dividing their responsibilities between the research and design phases. Although this is understandable, it regrettably limits the learning opportunities for students.

DESIGNED DENOUEMENT

There are profoundly unique technical benefits of integrating this scope of work into the structural design education of young architects. By applying their technical knowledge towards a daunting, but important and realistic architectural challenge, they learn that the relative efficacy of their design interventions are inextricably linked with their realistic engagement with a broad range of technical encumbrances. When considered within the totality of the design problem, the effectiveness of most technical solutions were only acceptable in relative terms—each decision seemingly effected others in ways that aren't readily apparent.

Although the parameters of the design problem are quite challenging, ultimately many students realized that constraints were beneficial to their work. It gave them a starting point for their design decisions, presented a framework for evaluative standards, and often helped them to see more complex nuances between different technical requirements.

Ultimately, many students discovered that design is a necessarily reiterative process of creation and evaluation that relies heavily upon in-depth exploration of complicated technical issues alongside a more holistic view of the world and our place as designers within it.

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