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DESIGN AND INNOVATION: ENGINEERS DO NOT MAKE THINGS

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DECADES OF DELUSION, HOW WE GOT HERE, AND WHERE IS HERE?

"Heresy/hɛɹəsi/(n): A controversial or unorthodox opinion held by a member of a group, as in politics, philosophy, or science."

—Wiktionary (https://en.wiktionary.org/wiki/heresy)

While we are at it, allow me to go one step further and say, "engineers ***shouldn't want*** to make things." The claim that "engineers don't make things" should sound counterintuitive, and to most engineers, it will sound like heresy. However, as we aim our collective sights on grand challenges and necessary innovations with an eye to the future, we are implicitly seeking to release ourselves from prescriptive and legacy approaches that have not been able to deliver by supporting the status quo. In this world of innovation, a little heresy is a good thing.

While many trace the origins of the Maker Movement to recent organizations encouraging young people to rapid prototype with 3D printers and laser cutters, making is undoubtedly rooted in a deeper and innate human desire and need to create solutions that address challenges we have faced as species across centuries. In the 1900s, before the widespread access to digital tools and precision fabrication, adherents to the movement would have simply been known as DIYers and hobbyists. While these clever individuals have certainly been part of crafting solutions that make their way into industrial applications, it is not a goal or requirement that their systems work beyond their application to a hyperlocal problem that the hobbyist themselves faced, and sometimes it is even acceptable that a solution does not work at all, as long as the hobbyist enjoyed the process of making it.

Hopefully, as we follow the logical pathway of the hobbyist origins of being a "maker", it becomes clear that we are no longer in the same realm of expectations as those that arise when we think of the responsibilities of an engineer. This motivates much of the way I work with undergraduate engineering students. Fighting the temptation to focus on that legacy hands-on approach that feels safe and reassuring is part of recognizing the future potential of engineering to provide answers that are not limited by humans acting as calculators, machinists, or hobbyists when trying to tackle serious problems.

Over the next few pages, we will unpack the reasoning behind "engineers don't make things" and "engineers shouldn't want to make things" to reveal interesting insights, beyond philosophical debates about engineering roles, into understanding markets, value creation, and attuning our senses to weak indicators that help predict the future.

THAT WHICH IS ENGINEERING OR WHY NAMES MATTER

"What's in a name? That which we call a rose by any other name would smell as sweet."

—Juliet (William Shakespeare)

Shakespeare was, no doubt, correct about roses, but the converse is not true; not all sweet-smelling flowers are roses, and this logical fallacy can help inform our understanding of the roles of not only engineers but also the other familiar characters in the chain of innovation and value creation.

In Silicon Valley, engineers are the lifeblood of the technology industry and are handsomely rewarded for the long hours and expert thinking that lead to innovative products and companies. In other parts of the world, though, engineers are merely implementers of specifications received from higher up in the chain of command, and there is little or no expectation that the job requires new thinking beyond rote repetition of pretrained skills to crank out work as it has always been done. In yet other parts of the world, the title "engineer" broadly describes any job that might be more accurately understood as technician or handyman. Whereas, the classical definition of engineering describes a profession in which individuals understand, interpret, and apply the natural laws of science and mathematics to create practical outcomes that benefit society.

In the United Arab Emirates (UAE), for example, local newspapers publish annual salary guides for jobs in the region. In 2022, a search for "electrical engineer" in such a list returns an expected starting salary of 9,000 AED per month ($29,379 per year) with a maximum of 13,000 AED per month ($42,437 per year). At face value, this seems impossible—this is the salary for a professional with a degree in engineering in one of the world's wealthiest economies; yet, the pay for this apparently respected career is barely enough to cover living expenses in Abu Dhabi.

Of course, it is not a mystery what has happened here. The title of "electrical engineer" in the UAE is generally accepted to describe an individual who lives in a shared staff accommodation, wears steel-toed boots and a company-issued uniform, and spends the day repairing electrical distribution panels and climbing ladders to pull cables and service building infrastructure.

Although electrical engineers in Abu Dhabi and Silicon Valley similarly produce and refer to schematic diagrams to understand circuit layouts and use test equipment like oscilloscopes to analyze electrical systems, they are fundamentally doing very different jobs. In the same way that a self-taught coder and a computer science graduate may use similar tools to capture ideas and test them on a computer, the coder could bash away at the keyboard for 1,000 years and would likely not be able to craft a new encryption algorithm that a computer scientist can create while using the same tools. Herein lies the paradox, not so much in naming, but in false equivalencies in skills, abilities, responsibilities, and value creation based on using similar tools.

In more recent years, UAE national salary surveys have expanded to include additional job titles with the word "engineer" for positions in the realm of software development with better associated salary bands. However, a gap in understanding remains, and as arbitrary as it sounds, I posit that without clarity on these titles and roles, it is challenging to build an innovation ecosystem with technology founders working on globally unique ideas and innovations. When the architecture of the technology of a company is generally seen as something to be farmed out to an overseas contractor, there is a shift away from owning a fundamental portion of the value creation chain.

This conclusion—do not outsource—seems to fly in the face of the title of this chapter; however, it is an intentional provocation. While "engineers don't make things" does imply a need to engage with a hierarchy of external suppliers, subcontractors, and fabricators, it also requires a dynamic strategy to ensure an organization remains vibrant and viable by retaining portions of the value creation chain that are challenging and rewarding for their internal teams.

CASE 1: VALUE CREATION OR NOT BUILDING BRIDGES

"Any idiot can build a bridge that stands, but it takes an engineer to build a bridge that barely stands."

—Unknown

In civil engineering, the above quote is a reminder that, given the task of creating a level crossing of a valley or gorge, any group of humans, given enough time and access to sufficient resources, could pile up materials to bridge the gap. On the other hand, to create a lightweight structure that spans the gap, using the fewest materials, while meeting all operational constraints, requires a kind of thinking that an engineer is uniquely qualified to do. The engineer must reconcile the geology of the site, the usage requirements, and the climate conditions with their knowledge of statics, dynamics, structural analysis, material science, and safety factors to arrive at an efficient design that society will be asked to accept as a safe and effectively invisible addition to their daily lives for decades to come.

Wrapped into this engineering design process is all the trial and error, testing, physics, and mathematics that prior generations of engineers and scientists have done to lay the groundwork for a modern engineer to make informed decisions without having to repeat each from scratch. The fact that regulatory bodies have created standard units of measure frees the engineers from creating their own each time. The fact that all materials used will have been destructively tested by their fabricators empowers the engineer to use the materials with confidence in their performance characteristics. Physics, at these scales, is well understood, and material and structural properties can be encoded into equations that computers can use to estimate the loading, fatigue, and lifetime performance of a proposed structure at the macro scale.

The act of engineering "a bridge that barely stands" suddenly becomes a very well-supported process, vastly different from the group of non-engineers haphazardly piling up rocks. Most importantly, the civil engineer, in the modern era, is responsible for the design of the system to ensure it is safe, practical, affordable, and performant within the bounds of the requirements. They will, however, rarely, if ever, lift a single finger or burn a single calorie building the bridge. This is the domain of contractors and construction crews. These teams notably have "site engineers", "field engineers", and others whose titles include the word "engineer" in their job descriptions. Site engineers are present to interpret drawings, prepare and oversee processes, and orchestrate groups of workers and equipment to ensure the structure is built to specification. It is crucially important, however, to realize that 100% of the engineering design and system-level thinking happened before ground was ever broken, and even though a bridge was made, the engineer did not personally take part in fabricating it.

CASE 2: SELECTING THE RIGHT TOOL OR NOT MAKING AIRPLANES

"At that time (1909) the chief engineer was almost always the chief test pilot as well. That had the fortunate result of eliminating poor engineering early in aviation."

—Igor Sikorsky

In thinking about orchestrating the creation of something new, it is natural to consider what it might be made of and which tools might be required to make it. Established organizations working on innovations often have the luxury of owning in-house fabrication equipment that, on the surface, seems as though it would inspire and enable the next generation of ideas. However, it is worth considering the age-old saying, "when you hold a hammer, everything looks like a nail" in the context of whether such "fortunate" organizations are, in fact, burdened by and bound to this equipment rather than enabled by it. To understand this more deeply, and begin to motivate why "engineers shouldn't want to make things", it is helpful to consider the Boeing 777 program that experienced a parallel dilemma in the 1990s:

"The 777 was the first commercial aircraft designed entirely by computer. Each design drawing was created on a three-dimensional CAD software system known as CATIA, sourced from Dassault Systemes and IBM. This lets engineers assemble a virtual aircraft, in simulation, to check for interference and verify that the thousands of parts fit properly—thus reducing costly rework. Boeing developed its high-performance visualization system, FlyThru, later called IVT (Integrated Visualization Tool) to support large-scale collaborative engineering design reviews, production illustrations, and other uses of the CAD data

outside of engineering. Boeing was initially not convinced of CATIA's abilities and built a physical mock-up of the nose section to verify its results. The test was so successful that additional mock-ups were canceled. The 777 'was completed with such precision that it was the first Boeing jet that didn't need its kinks worked out on an expensive physical mock-up plane', which contrasted sharply with the development of Boeing's next new airliner, the 787."

*—Wikipedia (*https://en.wikipedia.org/wiki/Boeing_777*)*

The move away from the legacy approaches of model making and testing for the 777 program was a culture shift that likely left many in leadership and across engineering teams feeling uncomfortable. In the end, however, it became empowering and financially advantageous to adopt a strategy of using well-crafted digital tools to prove performance characteristics without ever performing destructive testing.

In the same way, as engineers in the year 2022 develop new concepts and architectures, there is an expectation that tools used previously should be critically assessed to determine if they retain the qualities needed going forward. Additionally, the state of the art in computer simulation has improved markedly since the 777 program in the 1990s, so it is fully expected that engineers will seek to build or link together simulation environments to stress test and prove the performance of a design without the need to commit to permanently and irreversibly transform materials for each experiment. This further extends to the possibility that human optimizations might be supplemented with multidomain optimizations powered by automatic processes running in the background to assist in improving the quality of overall answers.

CASE 3: GETTING SMART IN THE RIGHT WAYS OR NOT MAKING ELECTRONICS

"I can't make you the smartest or the brightest, but it's doable to be the most knowledgeable. It's possible to gather more information than somebody else."

—Tony Fadell, "Father of the iPod"

When in search of innovative engineering ideas, there is a tendency for those conditioned by the global higher education system to see a need to enroll in a program, sign up for a class, read a textbook, or, more generally, receive validation from someone else that their learning on a subject has been sufficiently proven to be complete. As Tony Fadell alludes to in his 2022 book, Build: An Unorthodox Guide to Making Things Worth Making, the pursuit of knowledge, in the form of information gathering and sense-making, is an endeavor in which most humans can excel, regardless of courses taken or degrees held.

To take it one step further, we can both extend and invert this to say, "especially if you hold an advanced degree or have taken a course on a subject related to the area in which you're working, deciding what to work on or how to create an innovative idea should always start with information gathering, of which 99% will likely not show up in your final product idea but will support and strengthen it."

Students often enter labs, such as the one I run at New York University Abu Dhabi, full of energy and ambition, convinced that they have uncovered the formula for the next big thing. One student years ago came bounding into my lab, excited that he had invented a phone to dethrone, iPhone. In what for many seasoned advisors, is a telltale sign that something was off, he insisted that I sign a nondisclosure agreement (NDA) before he told me about the concept. I told him I would not and went on to explain why; at that point, Apple had released its last iPhone 10 months prior, so it is highly likely that a tech-focused young person would have seen many new technologies discussed publicly that he would think should be in the iPhone. I told him that, without hearing his ideas, I could imagine he had essentially crafted his "iPhone Killer" to contain all those components. Was I right? I will never fully know because I did not sign the NDA, but he began engaging with my line of reasoning.

It follows, I told him, that the crucial defining features of the iPhone have very little to do with the technology inside; once Apple made the big splash of introducing the world to an all glass smartphone with touchscreen in early 2007, the appeal of the iPhone is not so much that it competes on technology but that Apple ruthlessly maintains a launch cadence and develops products in a veil of secrecy that makes government intelligence agencies jealous. And, in the end, a man stands on a stage and will describe a device that was wholly unknown to the world up until he describes it; yet, that device will be in stores around the globe next week.

So, I continued the thought exercise with my student. Which features will your imagined phone have? Which suppliers have you lined up to provide the raw materials and components? How big is your software team who is writing your operating system or adapting Android? When will production begin? How will it be distributed? How will it be marketed? How many will you make? How will you ensure no one copies your design? Which regulatory bodies do you have relationships with? And how long will the process take? At the end of our conversation, we both agreed that, as a student, what he really should be doing is preparing to interview for an internship at Apple.

This is not to say do not take on big challenges; to the contrary, big challenges or big hairy audacious goals are what drive and sustain talented and motivated innovators and entrepreneurs. Although, as we have done many times in this chapter, the converse is not true: simply taking on an unreasonably large challenge does not magically elevate you to be ready to deliver. The "wantrepreneur" who is naively ready to boil the oceans because the predicted total addressable market size suggests they will be the next Musk or Bezos is likely more focused on the reward than correctly scoping and strategizing the work needed to get there.

While Apple has become the highest value company on earth, it did not do so by insisting upon keeping all operations under one roof. As we saw in previous sections, Apple also strategically divided its design and manufacturing to leverage the efficiencies of global markets. I encourage my students and others undertaking organization or product building to do the same where possible, ensuring the decisions about system architecture and overall vision remain firmly in their hands while finding ways to leverage off-the-shelf commoditized products and services. For the electrical engineers, I tell them it is not important to be skilled in soldering and assembling prototypes on breadboards; your design should be squarely digital and inside a computer that can help you simulate, analyze, and justify its production, and when the time comes, you should look forward to a robot fabricating and assembling it for you.

CASE 4: MESSING IT UP OR INSISTING ON DOING IT THE OLD WAY

"In the absence of clearly-defined goals, we become strangely loyal to performing daily trivia until ultimately we become enslaved by it."

—Robert A. Heinlein

In my role as a faculty member in engineering who runs a laboratory that is accessible to all students, I have the good fortune to have frank and lengthy discussions with students about their final year capstone projects. My approach is to assume the position of co-investigator who is equally curious to understand their challenges and search for a good and novel outcome, not simply an academically sufficient answer.

Given the progress in automotive self-driving offerings across the industry along with the ease with which artificial intelligence (AI) and machine learning can be implemented, trained, and utilized for computer vision problems, one of our recent graduates was encouraged by a faculty member to undertake the task of implementing an aftermarket self-driving controller that could be added to any car. While this is an interesting challenge when scoped properly, the process, as it played out in reality, can serve as a cautionary tale.

Instead of posing a question, both the faculty member and the recent graduate adopted a position of ignorance and a sense of presumed expertise on the subject because they either had studied or were studying related engineering topics. This meant that they gave themselves permission to skip doing research and jump directly into a proposed hardware architecture—it should be a raspberry Pi microcomputer with a depth-sensing camera attached. With that, they both agreed and moved forward to work on implementing the details, "enslaved by the trivial" as Heinlein would say. Without taxing your imagination, you can guess that the outcome was neither performant nor impressive.

Had the pair initiated a more authentic search for the best answer, assuming that their knowledge of the field might not be comprehensive or perfectly up to date, they would have begun digging—reading papers, setting up automatic news alerts, listening to podcasts, reading company filings, and searching patents—to fill their minds and hard drives with mountains of information that would become the foundation for a more informed approach.

They would have heard about and discussed comma.ai, a company founded in 2015 by George Hotz, famous for being the first person to remove the iPhone SIM lock in 2007 as a 17-year-old, which led to the ability to use iPhones with mobile providers other than those with which Apple had exclusive contracts. His driver-assist start-up was working on exactly the idea initially proposed by our students and faculty, and George's team's years of research and development were sitting in a freely available GitHub repository. This could have served, at the very least, as the benchmark against which the pair would aspire to outperform.

Instead of creating a blind spot by dismissing industry progress in self-driving as an unuseful source of knowledge compared with the work being done in academia, the pair would have watched and rewatched Tesla's AI Day presentation, devoured the Two-Minute Papers YouTube channel, and specifically sought out the findings from NVIDIA's research as well as industry contributions to journals and conferences. They would have been exposed to new thoughts on how to build, train, and deploy these types of systems at scale and would have understood more deeply the scale of their hardware requirements.

It should come as no surprise that, without an ambitious and well-defined set of goals determined by a well-informed view of the problem space, the outcome of such a project can only be a wishy-washy technology demonstration that is hard to defend.

When we presume that an epiphany, some kind of a spark of divine intervention into our thinking process, is what leads to innovation, we are often stuck in a loop of self-delusion in thinking that invention by epiphany is a common or desirable source of new ideas. Deep down, we are hoping for that easily explainable flash of inspiration that will make a great graduation speech when we are rich and famous. However, as Mark Twain said, "It usually takes more than three weeks to prepare a good impromptu speech. Overnight success is a fallacy. It is preceded by a great deal of preparation." From this, we can escape from under the thumb of magical thinking and realize that as we are building up mountains of knowledge on a subject, we are, in fact, developing intuition, and from that intuition, new connections will appear in our view, on the horizon, that others cannot see because they have not climbed the mountain yet.

FROM ENGINEERING TO ENTREPRENEURSHIP OR SWINGING THROUGH THE MVP

"Obsolescence never meant the end of anything, it's just the beginning."

—Marshall McLuhan

The discussion of engineers and making directly relates to thinking about the future of higher education, but it is, in fact, an allegory of the entrepreneur's journey: market research, technology debt, and architecting solutions for scale, beyond the Minimum Viable Product (MVP).

Alongside the myth of engineers as tinkerers and makers is the myth of renegade founders slaving away in a shed, garage, or dorm room, MacGyvering their first products out of sheer will and determination. These tales serve to inspire and make excellent founder myths, but they are particularly unhelpful in imagining how a new founder should move forward on an idea of their own. While the MVP is a goal post in the journey of many entrepreneurs, it is worth reflecting on what compromises are required to get it off the ground and how, as a founder, you are either burdening your future self by acting too much like a "maker" early in the process when there might have been opportunities to position yourself to see beyond the MVP, or having it simply be a blip on the larger roadmap to operating at scale.