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Experience-driven Engineering in IoT: The Importance of User Experience for Developing Connected Products People Love

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Experience-driven Engineering in IoT: The Importance of User Experience for Developing Connected Products People Love

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Abstract:

In this paper, we describe the factors we have seen as influential in building contemporary tools specifically through the lens of connected devices and experiences. The Internet of things (IoT) provides a radically improved way to see how our tools/devices actually perform in the field and if customers use, abuse, or do not understand them. The complexity associated with designing a connected product or experience often causes its architect to focus almost exclusively on the enabling technology itself as opposed to the actual design and end user experience—the value or utility—that they create it for. We walk through fundamental design principles. This paper provides principles, frameworks, recommendations, and resources to ensure human-centered and user experience-led design for the IoT.

Keywords: IoT, IIoT, Cold Chain, Green Supply Chain.

Soussan Djamasbi and Diane Strong were the accepting senior editors for this paper.

1 Introduction

User experience as a domain has existed in one form or another since the earliest humans began making tools. Design principles drive user experience and constitute key components of any tool.

1.1. Design Principles: Mean vs. Mode

Tools implicitly exist to solve problems. As humans invented more and more single-purpose tools, commonalities became obvious, and they could develop more general tools to solve multiple problems. An inherent conflict arises between single-purpose and general tools. A similar conflict arose as single-purpose tools (e.g., a potato peeler) became mass produced. Although designers still intended these single-purpose tools to solve the same, single problem, the requirement for people with varying skills, strengths, and other abilities to use them has pulled design in two directions: to the mean or to the mode.

Designing for the mean tries to treat all people as small deviations from a singular, idealized form. We know this thinking to involve flaws since humans differ from one another in many ways. Designing for the mean results in tools that can "sort of work" for many but which are not great for any.

Designing for the mode looks for a single archetype and optimizes for a subset of users. More practically, designers find archetype clusters and make variations in the tools that suit each archetype. They can do so via theorizing pseudo-personas or surveying real people to identify and describe a persona that represents the cluster (also known as segmentation).

1.2. Relevance to Internet of Things (IoT)

In this paper, we describe the factors we have seen as influential in building contemporary tools specifically through the lens of connected devices and experiences. The Internet of things (IoT) provides a radically improved way to see how our tools/devices actually perform in the field and if customers use, abuse, or do not understand them. We now have amazing capabilities to understand and tune devices' operational characteristics to suit individuals in a similar way to purpose-built, individualized tool development. However, it can be complicated and expensive to create the proper frameworks and support the working styles needed to deliver on the promises we see made possible through digital transformation.

Gartner (2019) defines the IoT as "the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment". Broadly speaking, and for our purposes here, we refer to the IoT when a sensor/actuator/device generates information in the physical world and sends/transmits it to the Internet (cyber/physical systems).

2 Definitions and Level Setting

While we have seen thousands of industrial IoT deployments that have varying degrees of complexity and scale, the field changes so quickly that it would not be prudent to argue some empirical model about "how one should do things". Nevertheless, we would be remiss if we did not summarize the key theoretical and practical concepts that influence contemporary tool design.

2.1 Human-centered Design

By its fundamental nature, design should be useful. Typographers anguish while crafting fonts with some intention. One might aim to optimize for legibility at small sizes and another might aim to optimize legibility for drivers zooming past billboards. A graphic design might use color to draw people's eye to a single object, to contrast two adjacent objects, or to evoke emotion. Design without intention will inevitably be mediocre at best and useless at worst.

Don Norman's (2013) seminal "Design of Everyday Things" reads just as validly today as when it first appeared, and we suspect it will remain relevant for many years to come. Norman uses the design intentions of everyday objects to show how even a little bit of thought and empathy can take products from tolerable to enjoyable.

However, we first dispel the notion that "if the product works, then it is at least tolerable", which represents user-hostile thinking because forcing—often unintentionally—extra effort, pain, or responsibility on users can quickly take one's product from tolerable to unbearable. The ease with which companies can enter new markets today means that product companies have walls and moats to defend against competitors.

As we continually digitize products and processes, a few fundamental considerations can dramatically increase one's chances of success.

2.2 Affordances

In this paper, we use the term affordance to refer to a design attribute that conveys how one system interacts with another system. People often conflate affordances with interfaces. While they relate to each other, they do not constitute the same thing. On a website, a link is an interface that allows users to navigate from one piece of content to another. The line under a link is an affordance. This underline provides a cue to users that something differs about this text. It is not just meant to be read but also clicked. Color to indicate read status (i.e., blue for unvisited and purple for visited) represents another link affordance, though we have almost lost this particular one..

We challenge readers to find a Web designer in 2019 that leaves link text with the default affordances. Many web designers change the primary color to some brand-friendly color. They also seldom used color to indicate read status, and, even when they do, users may not know which color means which. Not using familiar affordance becomes hostile to users when one has link-heavy webpages that users need to thoroughly consume, such as training guides and other documentation.

Of course, one does not necessarily need to underline text or use different colors for it for users to figure out that it allows them to navigate to other content. Headings seldom have underlines, yet we know we can click them through learned experience and convention. Websites connect content, so, when we see large words grouped together, we assume they constitute an interface to learn more information about that topic. The font's size and words' brevity urge users to click to learn more.

We do not mean to imply that affordances are static or absolute. Volkoff and Strong (2013) explicate affordances as a construct that conveys users' potential to achieve a goal. We try to use congruent yet simplified examples in this paper with one system being a human and the second system being a connected device.

2.3 Dissonance

Dissonance in the interface design context refers to when affordances do not imply the correct action, such as when a missing underline means users do not know which text links to another document or when text uses underline for emphasis rather than a link. In both scenarios, the expected outcome differs from users' expectation.

2.4 Feedback

When designing for emerging platforms in particular, designers need to take extra to prevent false affordances from leading to user frustration. The IoT and other machine-to-machine experiences further complicate interfaces as the many tasks each system attempts to accomplish can vary widely. Users require feedback (in form of success or failure messages) to adapt to complicated or unfamiliar interfaces.

Task failure needs to result in an obvious message either to the requesting human or machine with information that allows iterative training and increased usability—the ability to accomplish a task free from errors (Laubheimer, 2015).

3 Applying Human-centered Design to Business

Alan Cooper (2018) describes applying human-centered design as "an inversion of the way you do business". He explains that:

> *We no longer say to clients, "What do you want us to build? We'll build it.". Our partnerships are collaborative. We ask clients about their vision for their company. Then we must understand what the marketplace looks like, how people are using the product or service, and the goals the company wants to achieve. And marshal technology to get them there.*

Cooper's explanation points to a fundamental flaw that causes many IoT projects, programs, and, ultimately, products and services to fail. Many organizations act like hammers and treat each IoT project as a nail. In other words, project and program managers act in a myopic way, see the technical issue they need to solve, and, in a single dimension, look for the right technology to solve it. While such an approach might work in a traditional project or program (i.e., coding in a single language for a basic website), IoT project design requires much more holistic and human-centered thinking. The technology applied to solve the problem should really be the last consideration (as opposed to the first). Instead, one should employ a process based on user design and experience (both of the final product and the steps it takes to get to that product). We advocate a "think-design-build-run" approach.

3.1 (Norman) Doors from a Technical Perspective

To simplify things for explanatory purposes, consider a common object we all interact with daily: a door. Norman (2013) explains that if anything should be simply and intuitively designed, it's a door.

What use does a door accomplish? First, it separates two spaces. Second, it allows a user to voluntarily and temporarily move the plane to join the two spaces. The door has some interface allows the user to initiate the method to open or close the door (e.g., knobs on residential doors or bars on commercial ones) and attributes about how it might open.

3.2 (Norman) Doors from a Functional Perspective

A door can open in two possible ways, and almost always in a single direction: inwards or outwards. How does one know? The user can either guess, or the design can provide an affordance that helps people. For commercial buildings, external doors should have horizontal handles for people to push and vertical handles on the side for people to pull. Why?

The orientation of the bar provides a subtle hint—an affordance—about how people should interface with the door. Based on people's shoulders, wrists, and hands, a horizontal bar invites one to grasp and push. We can apply maximum force to push in this configuration. While we should not have to push doors hard, from our learned experience, we have learnt to push with square shoulders, straight arms, and straight hands. However, one cannot easily push a vertical bar. This visual feedback indicates that we need to try something different. People can quite easily pull using one arm.

Unfortunately, aesthetics often cause designers to make users fail their task and feel dumb. So many designers lose sense of functionality and, to continue the door example, have matching bars in the same orientation on a door for aesthetic purposes. We can find this error often with glass doors. Designers must not fall to the temptation to make something beautiful at the expense of users. This door scenario appears so commonly that it represents of the earliest academic examples for students who study human-centered design (Sundt, 2018).

4 Framework for Applying Human-Centered Design to Business

Doors have existed for millennia, and we often still design them poorly. What hope do we have in today's fast-paced world? Iteration! Designers should focus on testing their design decisions early and often with real product users.

As opposed to linear and single-dimensional thinking, we can view IoT project design as a series of concentric circles—an iterative process with multiple inter-related parts with a single common center. Viewing the project in a more holistic way and considering how modifications to one "circle" or part of the project affects the others enables designers to continuously develop products throughout the process, and it results in a much more effective product or end result. Designers can use the think-design-build-run framework (Rajguru, 2017) to assist with human-centered design.

4.1 Think

Apply design thinking principles and think holistically to solve the problem at hand. View the problem through the lens of strategy first (the expected return on investment (ROI) or business outcomes one looks to achieve), design second (how to execute against the strategy in the most pleasing way with the traditional trade-offs of cost, time, and quality in mind), and technology last (what tools will most effectively meet the requirements of one's strategy and design decisions).

4.2 Design

Designers should chart how they will put together the best possible experience across the ecosystem of people their product or service will touch. They should start with the end user who will derive the final utility from what you have built but also account for the multiple potential actors across the product or service lifecycle who may interact with the product or service. Ensure broad, big, and bold thinking; bring multiple perspectives and multiple disciplines to the design table—designers need diversity and inclusion, which result in varied thoughts and perspectives.

4.3 Build

Iterate. Iterate. Iterate. Apply the lean startup methodology (Ries, 2019) principles and approach (especially around the minimum viable product (MVP)). Beware the “can’t see the forest for the trees” adage—designers typically deal too closely with problems to properly assess them on their own as a project unfolds; constantly bring in others to test and validate. Focus groups and surveys are good, but anthropological methodologies (i.e., visual ethnography) are better—designers can watch people interact with their product or service and learn and improve based on those interactions.

4.4 Run

Once designers have launched their product or service, with any connected (IoT) product in particular, the user experience and customers’ relationship with the manufacturer and product itself does not end. At this point, the IoT’s true value comes into play both for producers and the consumers. Companies can aggregate information about their products deployed globally and learn when parts might fail or break in advance (predictive or conditional maintenance), find new or unexpected usage patterns, send over-the-air updates or patches to fix issues or improve functionality, and, ultimately, influence the next product revision or version through better contextual data about its usage. Some form of command and control center for the products once they are with end users is key. As this data comes in, it starts to turn into insights, which turns into knowledge, which enables action. Digital twins of physical products can enable one to run simulations without touching the “real” or “physical” products themselves (once one has accurate-enough algorithms based on real usage). Eventually, full business model transformation becomes possible, which includes the potential for product to service transformation (selling as a service as opposed to a single product; a shift from capex (capital expenses) to opex (operational expenses), and the potential for longer and recurring revenue streams).

5 Impacts on Business Outcomes

The cost to enter markets has never been lower thanks to on-demand manufacturing (which includes three-dimensional (3D) printing) and cloud computing. It has become ever harder to get to the market first, build walls and moats, and easily fend off competition. Winners in the future will put the user at the forefront of everything they do because they know that happy, empowered users drive positive business outcomes.

5.1 Starting with Good Intentions

Talk to users and strive to understand their needs. One needs to ensure every product and feature on one’s roadmap has clear value. Being a fast follower (Anthony, 2012) has become less of a winning strategy. Additionally, conglomerates continue to move into adjacent markets. Indeed, most industries have no shortage of providers. Winners also prioritize delivering value to users versus building business stakeholders’ pet features or chasing their competition with a “we-have-to–have-that-too” mindset.

Furthermore, IoT deployments involve much complexity, and the manufacturing and/or value chain for any connected product has many stakeholders. Of course, ensuring good design includes thinking about each stakeholder’s perspective and always keeping the end user in mind first; however, it also includes considering all stakeholders who will “touch” the product through its creation and full lifecycle. In Figure 1, we illustrate this point with a whimsical example that depicts a rope swing and the stakeholders involved in creating and using it.

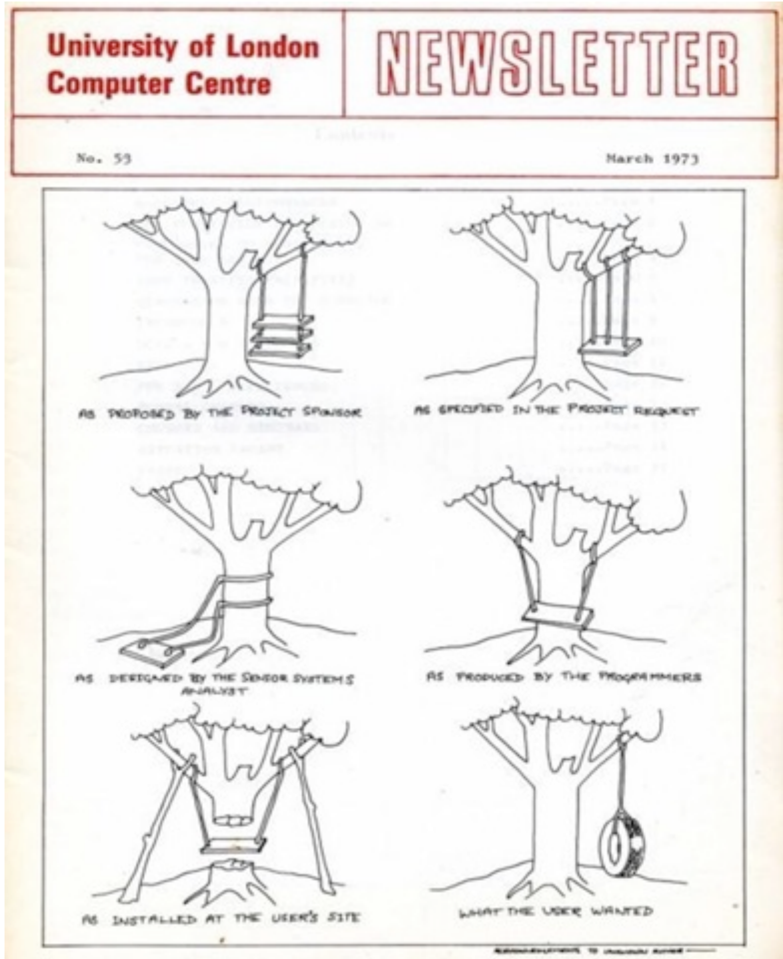

Figure 1. Rope Swing Example (SiteSmith, n.d.)

5.2 Follow Reference Architectures

Whenever possible, designers should attempt to leverage existing "commonly accepted" approaches vis-à-vis templates, patterns, frameworks, and architectures. Even in a fairly nascent space such as the IoT and when one works to create something truly innovative, others have likely thought of, if not directly attempted, something extremely similar to it. The old "don't reinvent the wheel" expression applies well here.

For any IoT project, program, or product-development process, one highly recommended resource comes from the Industrial Internet Consortium (IIC), a group of 240+ leading large enterprises, small and medium businesses, startups, and academic institutions all geared towards accelerating the adoption of the IoT globally. The consortium provides the "Industrial Internet Reference Architecture" (IIC, 2017), a free and easily accessible resource that can help designers as they consider technology for their IoT projects.

5.3 Idealism versus Reality

Designers will learn as they go. They learn more the faster they deliver products to users and see how they missed the mark. Make each incremental version just a little bit less bad. Eventually, one will have something pretty good. If we all accept that we will not be perfect the first time, we can actually start to work in a truly iterative, agile manner.

One primary component of being agile involves providing value to users through short iterations. Another primary and often overlooked component involves reducing uncertainty in projects by tackling the complicated, vague, and uncomfortable parts first. Given enough complexity, it might take longer to get a true minimum viable product (MVP) out the door, but the upside of better understanding what one truly needs to build pays off immensely.

5.4 Pay Now or Pay Later

One can hide one's mistakes forever. Whether designers catch mistakes early or after they have already delivered a product to end users, they will have to pay to fix them eventually if they want to have something the customer actually cares to use. One can make changes, fixes, or whatever kind of corrections more cheaply along the way compared to trying to do so at the end. A well-functioning product program requires one to set realistic expectations and adhering to high-quality standards. Accordingly, everyone on the team should be able to stop the assembly line to fix things earlier rather than later (Liker, 2004).

We also note the criticality of requirements documents and clearly stated statements of work (SoW)—especially in IoT projects but particularly for projects that one considers at least somewhat "innovative" (in other words, that it has an element of newness and a higher chance to fail). Referring back to our rope swing example (see Figure 1), when designers do something truly new and in a fairly nascent space, they need to set the project's scope and boundaries; otherwise, they will quickly find themselves stuck in "pilot purgatory" with little hope to scale or reap the benefits or ROI originally envisioned.

6 Universal Design for the IoT

Designers should not pay attention only to personas and pseudo-personas lest they make something many users will find awkward and even unusable. No average person exists. We all come in different shapes, sizes, and with widely ranging abilities. Design in a way that includes the edge cases.

6.1 Accessibility by Design

Referring again to Norman (2013), he tells the story of the founder of OXO kitchen utensils. Sam Farber saw his wife struggling to use standard vegetable peelers due to her arthritis ("Sam Farber", 2019). Farber, an industrial designer, added rubber to the handle to make peeler easier to grip. Not only could people with arthritis use the peeler more easily, everyone could. Farber designed for an edge case that resulted in a superior product and helped OXO become a market leader.

The Rehabilitation Act of 1973 made wheelchair access a requirement for all public buildings, and the requirement later extended to commercial buildings. One can meet the access requirement in many ways. Organizations often add metal ramps as a quick way to achieve compliance, but they give off a vibe of "we had to add this" rather than that they did it out of care and concern for equal access. Graded sidewalks and ramps represent a much more integrated approach that consider disabled peoples as primary and important users and not just people whom one accommodated for legal reasons.

Everyone has a disability at some point and to some degree whether permanent or temporary. Some twist their ankles or tear their knee ligaments. Others suffer illnesses that sap their strength and make "average" motor function impossible. Designing products and systems that allow for a broad range of user abilities creates more robust products with a broader market and with higher satisfaction.

6.2 Security by Design

Designers can include security more easily up front than later on. One should resist the urge to allow everyone access during development and "harden" later. If one does so, one will miss something important and spend a ton of money as well. Security by design is integral to the European Union's General Data Privacy Regulation (GDPR, 2019) because security incidents (big or small) will inevitably occur. By designing with security from the start, designers drastically reduce their attack surface and demonstrate to regulators that they hold the trust of their users as a core value.

6.3 Privacy by Design

Do not collect anything other than necessary to provide desired functionality. Now that IoT systems allow for massive data collection and ultra-fast sampling, one may find it tempting to instrument everything and toss it in a data lake. First, oceans with noisy data provide less help than smaller samples that include thoughtfully collected data. If designers have not considered the usefulness and interactions of their data, they could unintentionally create a privacy risk.

One should be clear to users about what one collects and why. The data belongs to users, and they grant access for its use in order to provide or optimize a service. Users do not represent data sources for one to harvest however one desires.

We might need to collect some samples of data to use for machine learning where we do not yet know what the data means or what privacy risks we may face. In these cases, one should anonymize at the edge. One does not need personally identifiable information to train an ML algorithm, so do not even collect it.

7 Conclusion

With so many relative failures with designs for simple things such as doors, accessibility ramps, and rope swings, we hopefully have not given the impression that we are doomed if and when we attempt to design connected products or cyber-physical systems. That certainly does not apply. While IoT product, service, or process design involves considerable complexity, if one follows the design principles we discuss and consistently keep the end user and the full user ecosystem in mind, one can avoid many of the pitfalls that common appear today.

According to Gartner (2017), the number of connected devices has already outpaced the number of people on Earth, and the number of connected things will increase from 8.4 billion in 2017 to 20.4 billion in 2020. Sensors and connectivity both in connected products on the consumer side and equipment outfitted with sensors/actuators/devices on the industrial side will not go away anytime soon.

As the world moves into greater and greater states of connectivity, we would encourage the millions of people architecting these products and services to not lose sight of the fundamental principles of user experience and design, or all of these connected devices will end up making everyone feel unconnected in the end.

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In his role as Director & Global Head of Partner Engineering (IoT, I4.0, Engineering Services) at Wipro, **Calvin Smith** and his team combine Wipro IP and services with Partner products and offerings to create differentiated End-to-End solutions designed to maximize customer ROI for specific use cases. Calvin also looks after the external ecosystem for Wipro IoT, covering analyst relations and academic research and engagement. Prior to this role, Calvin spent the better part of the last decade running IoT Strategy and Organic Innovation at Dell EMC. In the IIC, Calvin co-chairs the Smart Manufacturing Task Group and the Academic Task Group. Calvin has lived in eight states in the US, as well as in Scotland and Spain; and has travelled to over 50 countries.

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