Growing Impact of the Internet of Things: Design to Ensure the Future is Accessible for All

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

CJ Rogers

Spring 2021

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

I. Introduction

When thinking about the future and what the world might look like in 20, 50, or 100 years, a common theme is the prevalence of technology seamlessly integrated into day-to-day life. Technology will be in everything from clothes, furniture, roads, and mail in the form of Internet of Things (IoT) devices (Raj & Raman, 2017). The booming growth that IoT has seen in the previous few years has only furthered the idea that it will soon be everywhere (Bunz & Meikle, 2018). IoT devices are typically limited storage, low power, internet connected devices that feature sensors or other methods of collecting data that will be processed outside the device due to their small size (Dastjerdi & Buyya, 2016). Examples of such devices are Amazon's Alexa, electronic card scanners, the Apple Watch, and any device classified as "smart" due to intense processing occurring outside the device itself. It is estimated that by 2027 there will be more than 41 billion IoT devices, up from 2019's estimated 8 billion devices (Newman, 2020). Due to their small nature and relatively low cost, IoT has great prospects for those with disabilities. Certain devices are designed to monitor physical health or help remind users when to take certain medication. The potential to automate or assist with tasks that would otherwise be extremely difficult "can help make the elderly and disabled more independent" (Das, Tuna, & Tuna, 2015).

Currently, the accessibility of technology is considered an afterthought. Only once a product is shipped and implemented is accessibility considered. Assumptions made during the initial design process are ableist, and the same mistakes can be seen over time showing that "people have no idea of what is and is not accessible" (Brown, 2016). Universal design helps to change that mindset. By applying universal design through user-focused, accessibility will be baked into the design process allowing for the creation a better, more widely usable product.

In this paper, I argue that the most beneficial way to improve accessibility in future Internet of Things devices is to counteract technological momentum through cooperating with users with disabilities. Considering Neeley's definition of the discourse of design in comparison with technological momentum, will support the procedure and decisions made in universal design by shifting the focus to the user rather than the industry. The best way to ensure the proper choices are made during the process is to involve people with disabilities and design with the 1% in mind rather than the 99%.

II. Flaws in Current Design Methodologies and the Introduction of Universal Design

As mentioned previously, the current more popular approaches to design are ableist in their assumptions. Ableist or ableism refers to discrimination in favor of able-bodied, or non-disabled, people. Day-to-day operations that many able-bodied people take for granted are complicated by any number of disabilities. An article titled 'Design and Agency: When Design Fails the Disability Community' by Walei Subray (2018) gives an example of when technology, and in this case an example of an IoT device, used to accommodate those who are blind or hard of hearing while watching movies are riddled with issues. One of many issues is that the devices are often confused for one another by the employees, accidentally giving a blind moviegoer an assisted listening device rather than the audio description device. Mistakes like this are not only inconvenient for the moviegoer but the employees as well. The more apparent issue is the "design flaw … that blind users cannot set them up independently", since they feature "LED displays that have no audio or tactile feedback" (Subray, 2018, p. 2). What is the point of having a device designed to help blind people if they are not able to set it up or fix problems themselves? While the idea of having devices to increase accessibility is great, it is the design process that is flawed.

Technology should empower individuals to do and achieve more, and IoT has the potential for that (Subray, 2018; Part 12: Internet of Things, 2019), but in many cases it becomes an added weight. An article by Eryn Brown titled 'The fight for accessibility' (2016), outlines how the field of science and research has not been designed with accessibility in mind. It exemplifies the historical tendency to exclude physical disabilities from design considerations. The article describes situations where "eyewash stations are tucked into inconvenient corners" (Brown, 2016, p. 2) which makes them hard to access in cases of emergency. It's situations like this that show how small choices, like the location of an eyewash station, can have a big impact not only on convenience, but the overall safety of those with disabilities. She also mentions that in many cases "they may have to design their own equipment" as well (Brown, 2016, p. 1). The lack of support and accessible equipment for scientific researchers is then directly responsible for low employment percentages especially in STEM professions (Brown, 2016). Poorly designed environments and technology lead to a limitation on autonomy for these individuals as they rely on others to complete common tasks (Brown, 2016; Woyke, 2019; Das, Tuna, & Tuna, 2015).

Currently, one of the main processes for designing IoT devices is the software development process. This process can either take an iterative approach or a "waterfall" approach as outlined in Figure 1. Five main stages are featured (Hughey, 2009). First in the process is requirements, where the needs for the product are determined. Second is Design, where it is determined how the needs from the requirements section will be met. The third stage is implementation which refers to the process of prototyping and creating the product itself. The fourth stage is verification and validation, where the product is compared to the initial requirements to determine if it is an acceptable product. Last in the process is the maintenance stage. This stage takes up the most time and money, and when issues or bugs arise in this stage, they are much more expensive to deal with (Smith, Martinez, Marlowe, & Claypool, 2019). In the original waterfall model, it is not feasible to add more features to the product at the final stage (Hughey, 2009). In an iterative process, it is significantly easier, but still will take time once the product is deployed. Here lies the main problem with adding accessibility to IoT devices. The addition of accessibility related features tends to come during the maintenance phase of the process. The product is already being used by consumers before accessibility features are considered. Only once complaints arise will a solution be created and applied to the product. The resulting products are highly unusable to people with disabilities when they first come out, and it may be a long time, either months or years, before a usable solution is in place. To compensate for inaccessible technology, disability specific products are created to translate the unfriendly product into something usable.

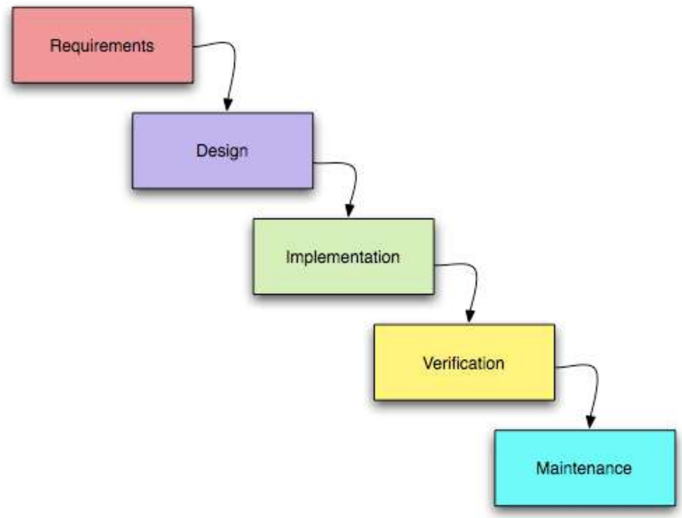

Figure 1: Outline of the stages of the Waterfall development process that is used in Software Development. While not as commonly used in practice recently, its stages are still widely used and referenced today *(Hughey, 2009)*.

Assistive technology (AT) is in many cases the intermediary between disability and usability for technology. Products such as screen readers, various listening devices from movie theaters mentioned earlier, closed captioning, and eye trackers are all examples of Assistive Technology (Part 12: Internet of Things, 2019; Smith, Martinez, Marlowe, & Claypool, 2019).

While there are many other types of AT, their general purpose is to accommodate for specific disabilities. By focusing on only one disability or type of disability, AT is able to serve much more niche areas that are hard to account for in a more general design (Part 12: Internet of Things, 2019). There has been success in both areas of AT, namely cooperative technologies that work together with general technology, as well as devices designed for specific types of disabilities. AT covers current gaps in IoT by creating new products designed for more niche disabilities, but it does require that more common applications, that abled people also use, to have a certain level of compatibility with the tools, so AT is not a complete solution.

Universal design (UD) is currently the best answer to inclusive, accessible design due to its thorough process and well-defined principles. The Center for Universal Design defines UD to be "the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design" (Burgstahler, 2009, p. 1). In another sense, this definition means going into the design process and considering how all people would use the application, disability or not. All of a person's characteristics, a concept called intersectionality, should be considered in the design process (Burgstahler, 2009). With intersectionality, it is not enough to consider one aspect of a user's profile, every aspect and how they interact with one another must be considered. Also known as a user-designed process, UD seeks to "put the user at the center of the design process by integrating the user into each aspect of the process" (Schulz, Fuglerud, Arfwedson, & Busch, 2014, p. 46). By focusing directly on a wide variety of users, both with and without disabilities, UD opens the door to more creative and accessible design choices.

Universal design has a very generalized process so that it can be applied in any environment for a wide variety of products. The process as outlined by Universal Design: Process, Principles, and Applications by Sheryl Burgstahler (2009) is as follows:

1. **Identify the Application.** Specify the product or environment to which you wish to apply universal design.
2. **Define the Universe**. Describe the overall population (e.g., users of service), and then describe the potential members of the population for which the application is designed (e.g., students, faculty, and staff with diverse characteristics with respect to gender; age; size; ethnicity and race; native language; learning style; and ability to see, hear, manipulate objects, read, and communicate).
3. **Involve Consumers**. Consider and involve people with diverse characteristics (as defined in Step 2) in all phases of development, implementation, and evaluation of the application. Also gain perspectives through diversity programs, such as the campus disability programs, such as the campus disability services office.
4. **Adopt Guidelines or Standards**. Create or select existing universal design guidelines/standards. Integrate them with other best practices within the field of the specific application.
5. **Apply Guidelines or Standards**. Apply universal design in concert with best practices within the field, as identified in Step 4, to the overall design of the application, and all ongoing operations to maximize the benefit of the application to individuals with the wide variety of characteristics identified in Step 2.
6. **Plan for Accommodations**. Develop processes to address accommodation requests (e.g., purchase of assistive technology, arrangement for sign language interpreters) from individuals for whole the design of the application does not automatically provide access.
7. **Train and Support.** Tailor and deliver ongoing training and support to stakeholders. Share institutional goals with respect to diversity and inclusion and practices for ensuring welcoming, accessible, and inclusive experiences for everyone.
8. **Evaluate.** Include universal design measures in periodic evaluation of the application, evaluate the application with a diverse group of users, and make modifications based on feedback. Provide ways to collect input from users.

While only a suggested process, it encompasses the need to both have a big picture view of the problem as well as a personal level focus on subparts of the project (Burgstahler, 2009). The process is made even more robust by adding a feature like iterative development (Schulz, Fuglerud, Arfwedson, & Busch, 2014). Iteration is a feature also seen in more modern software development as well as writing, and other engineering design. Iteration allows for modification of certain aspects in order to make the final product align more with the principles of UD.

The principles of universal design are the most important part of the design methodology. Where the process is more flexible to the scenario, as is, the principles are applicable in any situation and should not need to be changed. Their main focus is to cover as much of accessible

Principle	Guidelines	Importance for IoT
1. Equitable Use	Provide the same means of use for all users. Avoid segregating or stigmatizing any users. Provide equal availability for privacy, security, and safety. Make the design appealing to all.	Should not need to create/implement two or more separate devices to do the same job for different classifications of disability.
2. Flexibility in Use	Provide choice in methods of use. Accommodate right- or left-handed access and use. Facilitate the user's accuracy and precision. Provide adaptability to the user's pace.	Design devices to be adaptable for different methods of interfacing. Make it adjustable or make it ambiguous
3. Simple and Intuitive	Eliminate unnecessary complexity. Be consistent with user expectations and intuition. Accommodate a range of literacy and language skills. Arrange information in order of importance. Provide effective prompting and feedback.	Users should not need the assistance of a trained helper in order to use the device.
4. Perceptible Information	Use pictorial, verbal, and/or tactile modes for presentation of essential information. Provide adequate contrast between essential information and its surroundings. Differentiate elements in ways that can be easily described. Provide compatibility with devices used by people with sensory limitations.	Information should be readily available without being distracting or cluttering the information that a user will truly care about.
5. Tolerance for Error	Arrange elements to minimize hazards and error. Provide warnings and fail-safe features. Discourage unconscious action in tasks that require vigilance.	An incorrect click or invalid input should not change whether the device is usable, and issues should be similarly reported to the user.
6. Low Physical Effort	Allow user to maintain a neutral body position. Use reasonable operating forces. Minimize repetitive actions and sustained physical effort.	Avoid strain to the user, limit the amount of time or effort to interact with the device. Offer another form of interaction that requires less physical action.
7. Size and Space for Approach and Use	Provide a clear line of sight to important elements for any seated or standing user. Make comfortable for any seated or standing user. Accommodate variations in hand and grip size. Provide adequate space for the user of assistive devices or personal assistance.	In implementation of IoT, ensure that the physical device is reachable by any user no matter their physical state. If unreachable it becomes a hinderance to progress.

Figure 2: The seven principles of universal design that are outlined in a document from Pearson where they discuss the importance of universal design in education to accommodate students with disabilities *(Case, 2003)*. Importance added to highlight aspects related to IoT design.

design as possible. The principles of universal design were first published in 1997 by the Center for Universal Design and consist of equitable use, flexibility in use, simple and intuitive, perceptible information, tolerance for error, low physical effort, and size and space for approach and use. The principles that are outlined in Figure 2 cover a wide range of possible friction points for a variety of disabilities. It is the interconnections between the principles that becomes important. On their own they can be used to guide design, but without the right intentions, one of the principles could be missed, and the original problems that were trying to be solved, will quickly return. With these principles widely available, why have more teams not put them into practice when designing? What makes universal design so different from other techniques?

Universal design's principles give it a clear focus on users from a wide range of backgrounds from the outset of the design process when compared to other variations of the standard design methods as evidenced by the principles of UD. The previously mentioned "waterfall" method, as well as its iterative counterpart, have the potential to have that wide human-focused aspect but fall short. In their standard versions they are only concerned with "stakeholders", people who are directly affected by the technology (Hughey, 2009), not necessarily users with accessibility concerns. One altered version of the process creates a "persona" which is meant to represent the majority of target users (Faller, 2019). It shifts the focus of design to a more "human-focused" process but it does not yet satisfy the needs of the accessibility. In cases of smart cities, the vast majority of users will be able-bodied people, and the persona created in those scenarios will most likely reflect that (Smith, Martinez, Marlowe, & Claypool, 2019). A modified version of UD also features an improved idea of a persona and adapts it to be an "accessibility champion" who can be a voice for accessible design choices (Schulz, Fuglerud, Arfwedson, & Busch, 2014). The best example, and case of successful use of this accessibility champion, is Schulz, et. al.'s case study (2014). Their accessibility champion helps inform the choice of user personas that account for a wider user of the modified persona (Schulz, Fuglerud, Arfwedson, & Busch, 2014). With each of the cases of success and failure of accessible design, a set of tiers of design start to form, from no interaction and success to cooperation and resounding success.

Mapping the levels of success in accessible design to their source creates a pyramid that can also extend to show the possible barriers between them. At the bottom of the pyramid is the scenario that should be avoided at all costs; no interaction, no thought, no concern for users with a disability. Examples of this case are shown in Brown's article (2016) and touch kiosks in Woyke's smart cities (2019). One step up is compatibility characterized by the ability to be used with Assistive Technology. If it works with a screen reader or eye tracker, then it can fit into this tier. Next would be a tier exemplified by research. This tier is where developers start to account for disability in their designs, or are designing to solve a disability specific need, but do not yet test with affected users until after deployment. Subray's case of assistive hearing devices in movie theaters would fit this tier. The devices are useful and server their purpose well, but fall short of their potential. The consult tier follows after where designers consult with users with disabilities during the process of development at least once, such as during the

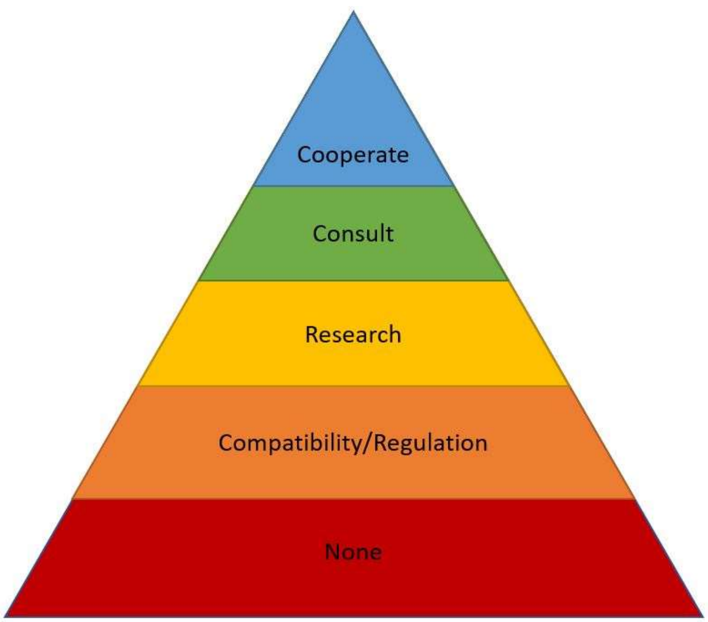

Figure 3: Pyramid to show how the progression of including accessibility in design is not a "yes or no" issue but one of progression and effort. Moving up the pyramid will take effort as it requires a different type of change from the standard process at each barrier.

creation of the "accessibility champion" (Schulz, Fuglerud, Arfwedson, & Busch, 2014). Finally, the top tier is cooperation. This tier fits projects that feature users with disabilities at every step of the process. Elements of this are shown in Moon's design of wearable technology (2019) and Ferati's smart shower design (2018). Both cases feature the authors conducting each phase of their design process alongside focus groups or individuals with disabilities. Both managed to create a product, while not perfect, that was useable for a much wider variety of users. This model then can account for different levels of involvement and the bare minimum in order for IoT to be considered accessible going forward. What it does not account for is why there is a tendency to stay at the bottom of the pyramid. What about designing IoT devices makes it so hard to cooperate during each stage of the process? If a procedure such as UD exists and is widely available, there is something stopping developers from applying it to their design methods.

III. Slowing Down Momentum to Strengthen Design

There is a growing sense of momentum and sureness when talking about the future of the Internet of Things. In order to stay relevant, companies must quickly adapt to the times and get a product out before they miss out on a possible market share. The adapt or fail mentality has led to a serious lack of accessible IoT in the market. The speed at which companies develop projects does not allow for the most basic level of cooperation mentioned previously. That is not to say there has been no success. There has been great success when accessibility has been considered from the outset of the design process as seen in the cases of the Moon (2019) and Das (2015) smart products. The extra thought and preparation led to more usable products, not just for those with a disability but also for the general public (Moon, Baker, & Goughnour, 2019). One of the greatest strengths of IoT is the extremely high potential to make an impact in the independence of every person who has a disability. With such a wide variety of devices in production, the coming years are a pivotal point in which IoT will either become the incredible support system it has the potential to be, or another hindrance and obstacle to overcome. The concept of momentum described here can be related to the discourse of inevitability presented in Neeley's 'Beyond Inevitability' (2008) framework.

The discourse of inevitability is primarily characterized as the quote "adapt or you're toast". During times of technological shift, such as the shift towards IoT devices, the growing popularity of that technology will cause a change in conversations surrounding them. Neeley describes inevitability as "first and foremost a marketing strategy". Questions change from "should we use it" to "which one should we use." This concept is prevalent throughout the description of the discourse of inevitability. Its main features are:

- Something that is common in pop culture
- Marketing Strategy
- Decisions are made between technologies not whether they should be made at all
- Technology is driver of social evolution
- Autonomous technology

IoT has certainly become common in pop culture. With jokes surrounding Alexa devices extremely common and every device in a home now being able to connect to each other, it is no wonder why they have become an integral part of today's culture. Smart marketing employees use these pop culture trends to further advertise their products, as they quickly change the expectations of the average person. You don't own a smart watch? Why isn't there an app for this? I still have to use a physical key? Questions like the ones mentioned and the "which type" questions will only become more common as development continues to move in to the "technological momentum" that Neeley mentions. The momentum created by the speed of growth is the key factor in why there is a lack of accessibility. As Moon (2019) describes, "users with disabilities should be utilized as part of rather than simply being subject to technological change." In technical development, according to Neeley, the developers are more concerned with how their device fits into a whole rather than the effect of the design itself.

Instead of further pushing the technological momentum even further along, the Discourse of Design should be considered. The method for how to "supplant the Discourse of Inevitability" according to Neeley, can be broken into three concepts:

- "recognizing the robustness of the discourse of inevitability derives from many sources, including the way it resonates with lived experience…which gives rise to its perceived simplicity and familiarity"
- "developing a compelling discourse of design … based in engineering and philosophy of technology"
- "demonstrating that as humans we have choices about the forms of discourse in which we engage and that those choices have significant societal consequences"

With these concepts, the way to shift from technological momentum to the discourse of design is to both acknowledge the origins of aspects of the discourse of inevitability, as well as seeking to move past it on an individual level. It is important to make the shift because in the discourse of inevitability "absent is a focus on people, lack of ethical concern beyond the question of functionality" (Neeley, 2008, p. 251). Especially when concerned with creating accessible technology, the design process should consider and focus on people, and not just one type of person, as in the concept of a persona (Faller, 2019), but people of all kinds. There is not going to be a singular answer to the accessibility question, but by considering all people as part of the user base, the technological momentum is slowed to allow for creative problem solving within the discourse of design. Creativity in “design leads to the manifestation of human intention” (Neeley, 2008, p. 255) and through that design can become more than just a means to an end for technology and IoT.

The benefits to modifying the approach to IoT design, by focusing on the discourse of design, would not just improve the lives of those with disabilities, but everyone. Greater originality in designs could lead to more widely usable solutions that could shift the typical level of accessibility from none to baseline compatibility. It would also make sure that designers and engineers put thought into their designs and whether or not they should be created in the first place. The principles of universal design focus on the human aspect of design and ensure that the process is thorough. With the concepts of supplanting the discourse of inevitability outlined here, it can be determined that there are ways to shift the basic level of compatibility to a place that will ensure accessibility on the minimum level. The place to begin is combining universal design and the accessibility champion with ideas from the discourse of design.

IV. Working with Disabilities Rather than Against; Shifting between Levels of Interaction

One of the key factors in the success of design is to involve and understand the people that are going to be directly impacted by the technology that is created. Both the original design method, the “Waterfall” method, and universal design (UD) have an applicable principle. In the waterfall method, one would take time during the requirements phase to outline what the end user wants and needs in order to create a successful product. Universal design principles are designed to inform the requirements process. Where the waterfall method falls short, the UD principles strengthen the process and widen the scope of the search for requirements. By widening the scope, UD ensures that accessibility features are included in the requirements, the start of the software development cycle. For IoT devices, the software is only one part of the whole solution. Another big consideration is how the product will be implemented, which is not something considered for pure software. For IoT, implementation will create the biggest difference between the tiers in Figure 3. The actual IoT device itself needs to be accessible not only to able-bodied people, but those with wheelchairs, crutches, impaired vision, etc. Similar to the example with the movie listening devices, if the user with a disability is not able to set-up the device themselves, then the design as a whole cannot be considered accessible by the UD principle of "Size and Space for Approach to Use" and could then fall into the none or compatibility tier, rather than the research tier. While the UD principles are a great start to understanding how to create designs that accommodate for disability, there is still an issue of "well-meaning non-disabled designers that fall flat of their goal of delivering independence" (Subray, 2018). I make the following claims that would help solve the issue of "well-meaning" in order to keep design choices from "[falling] flat".

1. *In order for universal design to be used to its fullest capacity, it must involve users with disabilities at every point in the design process.*

In the tiered levels of accessible design outlined in Figure 3, the most complicated line to cross is from research to consulting and cooperation. Directly interfacing with affected users with disabilities is hard when there might not be the organizational or cultural foundations for it to be facilitated. Life experience is one of the greatest teachers, so who better to help design a product meant to accommodate for disability than someone who has lived with that disability. The in-depth knowledge of what does and does not work is invaluable to a design team. There is only so much empathy and understanding that research can give, but having someone with disability working with the team from the beginning would make the design process much more effective from the earliest stages of design. The effects of involving users early on are most clearly seen in the case of smart shower designs (Ferati, Babar, Carine, Hamidi, & Mörtberg, 2018). Their team worked directly with paraplegic users to create prototypes that would benefit them most. The team was then able to use those prototypes to inform the next stages of their design. Even just this step would have strengthened their process, but they also involved these users at every stage which is why their project could be placed firmly in the cooperation tier of accessible design.

The most basic way to achieve sweeping changes to the design process is to involve people with a disability at every stage: Requirements, Design, Implementation, Verification, and even Maintenance. During the requirements stage, make sure to incorporate needs and abilities into the outline for the requirements of the product. In designing the product, confirming that the design will actually solve the problems it needs to and avoid making common design mistakes will help avoid the "well meaning" issue. Implementation, and by extension prototyping, is an opportune time to test in realistic scenarios to ensure that the product and environment work harmoniously. By testing on a wider scale, the following verification stage ensures that less modifications will need to be made late in the process. While the maintenance stage doesn't need to change all that much, where it becomes important is when a major update or change is made to the product.

As mentioned, the main issue with involving users with disabilities is the lack of organizational structure required to find and consult these individuals. What was absent from most of the case studies was a mention to how they reached out to the individuals that they worked with. In the one case it was mentioned, the team reached out to members of the Dyslexia Norway organization as well as one that works with seniors to learn about the internet (Schulz, Fuglerud, Arfwedson, & Busch, 2014). The solution for a country like the United States would be to either create an organization or partner with organizations that engage people with a variety of disabilities. They would serve to become an intermediary for smaller companies to consult on designs for new IoT devices. By creating a rapport between developers and the disability community, simple misunderstandings from "well-meaning" developers would diminish. Stopping to consider these types of organizational structures would also help supplant the growing technical momentum in the IoT industry by replacing one type of lived experience with another. Until such a time where the technology improves to allow for developers with disabilities to emerge in the field as their own "accessibility champion", they can still offer insight into solutions that will benefit the wider population.

2. *An accessibility standard for IoT devices must be set in order to assure that any device with the possibility to become widely used will be usable.*

As mentioned earlier, there is not much in terms of design standards for IoT devices, let alone for accessibility for IoT devices. In order to limit what is quickly becoming technological momentum, groups of designers in conjunction with a variety of people with disabilities should work together to determine some basic design standards for IoT devices. Creating a set of standards such as this would help shift the typical level of accessibility from none to compatibility. The main goal is to limit the effect of the discourse of inevitability and get the focus back on creative design and specifically on human needs. By creating a set of standards, accommodations for the most common types of disability can more easily be accounted for in design and allow teams that don't have the privilege coordinating with disabled users make acceptable design and implementation decisions.

Creating this set of standards would be most successful by combining the principles of UD with methods to support the discourse of design and supplant the discourse of inevitability. The combination of these factors would give the standards both actionable tasks to take during the design process and more high-level considerations to ensure consideration of the big picture. Involving the high-level itself will account for the need to include both “engineering and philosophy of technology” ideals outlined by Neeley (2008). While standards are a step in the right direction, there will still be many cases that do not align with them. What matters is that technologies that will be used on a wide scale in smart cities or other public settings will have adhered to it and ensure that there is a baseline of accessibility for any possible user through compatibility with assistive technology.

Lastly, having a set of standards would allow for the creation of frameworks or modules that teams with smaller budgets or individual developers could use. Frameworks such as this tend to be plug and play allowing the developer to focus on their application’s features rather than compatibility concerns. For a market like IoT, this type of freedom for smaller developers will only help further the technology being created in the long run. It would also have the side effect of helping people become more aware of designing for disability.

3. *Education for developers on Disability and Current solutions to certain common problems*

Other than the barrier from none to compatibility in Figure 3, and the barrier from research to consulting/cooperating, the hardest jump to make is from compatibility to research. Here the issues arise from not being aware of the possibilities of issues once the design has been rolled out. For smart city examples, the technologies may be compatible with assistive technology but there is a simple development change that could make another slight improvement. By educating developers and even just the general population about disability, they would have a better idea of some of the challenges that others face in day-to-day life. Developers then would have a better understanding of how influential those challenges are when interacting with IoT devices. It may also spark ideas for possible IoT based assistive technologies that could not only make the world more accessible, but help those with disabilities become more accessible to the world.

V. Conclusion

The end goal of implementing universal design into IoT is to ensure that there is a future in which people with disabilities are able to be as independent as any non-disabled person. IoT has the power to make that future a reality. Making sure that IoT is not ableist, and therefore exclusionary, to the people that could benefit from it most is the key. Changing the current process of design and development from one that thinks little of human interaction to one that focuses on universal design is imperative. Without the shift, technological momentum will continue to increase to a point where it will be hard to interject changes without serious force. The best way to accomplish this is to directly involve those with disabilities. By either involving them at every step in the process or simply seeking to understand their lived experience, the perspective of one such person will make a huge difference. Ultimately the goal of changing the focus of design should be to change the typicality of accessible design from none to compatibility with current assistive technology. Even such a slight change will change the prospects of people with disabilities and increase the level of autonomy that they can gain with IoT. While there are barriers to this move, by tackling them now with a set of standards the doors will open to more grand changes and technological improvements that could eclipse what anyone thought was possible.

VI. References

Brown, E. (2016). The fight for accessibility. *Nature*, 137-139.

Bunz, M., & Meikle, G. (2018). *The Internet of Things.* Cambridge, England: Polity.

Burgstahler, S. (2009, February 26). *Universal Design: Process, Principles, and Applicaitons.* Retrieved from ERIC: https://eric.ed.gov/?id=ED506550

Case, B. J. (2003, Dec 1). *Universal Design* . Retrieved from Pearson: http://images.pearsonassessments.com/images/tmrs/tmrs_rg/UniversalDesign.pdf

Das, R., Tuna, G., & Tuna, A. (2015). Design and Implementation of a Smart Home for the Elderly and Disabled. *International Journal of Computer Networks and Applications*, 242-245.

Dastjerdi, A. V., & Buyya, R. (2016). *Internet of things: Priciples and paradigms.* Cambridge, MA: Morgan Kaufmann.

De Saulles, M. (2021, January 1). *Internet of Things Statistics*. Retrieved from Information Matters: https://informationmatters.net/internet-of-things-statistics/

DeNardis, L. (2020). *The Internet in Everything: Freedom and Security in a World with No Off Switch.* New Haven: Yale University Press.

Faller, P. (2019, December 17). *Putting Personas to Work in UX Design: What They Are and Why They're Important*. Retrieved from Adobe: https://xd.adobe.com/ideas/process/user-research/putting-personas-to-work-in-ux-design/

Ferati, M., Babar, A., Carine, K., Hamidi, A., & Mörtberg, C. (2018, January 1). *Participatory Design Approach to Internet of Things: Co-designing a Smart Shower for and with People with Disabilities.* Retrieved from Lecture Notes in Computer Science Universal Access in Human-Computer Interaction: https://search.lib.virginia.edu/sources/articles/items/edsswe_edsswe.oai.DiVA.org.lnu.78060

Hughey, D. (2009). *The Traditional Waterfall Approach*. Retrieved from Comparing Traditional Systems Analysis and Design with Agile Methodologies: http://www.umsl.edu/~hugheyd/is6840/waterfall.html

Khan, J. Y., & Yuce, M. R. (2019). *Internet of Things (ioT): Systems and Applications.* Pan Stanford Publishing: Milton.

Moon, N. W., Baker, P. M., & Goughnour, K. (2019). Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors. *Technologies Engineering*, 1-12.

Neeley, K. A. (2008). Beyond inevitability: Emphasizing the role of intention and ethical responsibility in engineering design. In P. E. Vermaas, P. Kroes, A. Light, & S. A.

Moore, *Philosophy and design: From engineering to architecture* (pp. 247-257). Heidelburg, Germany: Springer.

Newman, P. (2020, March 6). *Internet of Things Report*. Retrieved from Buisness Insider: https://www.businessinsider.com/internet-of-things-report?IR=T

Part 12: Internet of Things. (2019). *Technology and Disability*, 195-198.

Raj, P., & Raman, A. C. (2017). *The Internet of Things: Enabling Technologies, Platforms, and Use Cases.* Boca Raton: CRC Press.

Schulz, T., Fuglerud, K. S., Arfwedson, H., & Busch, M. (2014). A Case Study for Universal Design in the Internet of Things. *Assistive Technology Research Series*.

Smith, L., Martinez, C., Marlowe, C., & Claypool, H. (2019). *The Internet of Things (IoT) and People with Disabilities: Exploring the Benefits, Challenges, and Privacy Tensions.* Washington: Future of Privacy Forum.

Subray, W. (2018, April 6). *Design and Agency: When Design Fails the Disability Community.* Retrieved from Cooper Hewitt: https://www.cooperhewitt.org/2018/04/06/when-design-fails-the-disability-community/

Woyke, E. (2019, January 9). *Smart Cities could be lousy to live in if you have a disability.* Retrieved from MIT Technology Review: https://www.technologyreview.com/2019/01/09/137899/smart-cities-coule-be-lousy-if-you-have-a-disability/