Discussing the Challenges in Creating an Online Library of
3D Printable Assistive Medical Devices

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Abstract

Our goal is to identify the barriers and process of creating a digital library of medical assistive devices that can be personalized and 3D printed ~~by~~ for people living with disabilities. In the past, and true today, traditional manufacturing methods make it cost prohibitive to create personalized devices to assist individual patients with their activities of daily living ~~needs~~. ~~However~~Now and in the immediate future, availability and affordability of 3D printing ~~now~~ makes it feasible to ~~generate~~ produce low volumes of devices, on demand, using a distributed manufacturing model. This document discusses three main challenges to originating and creating this library: (1) the validity of using 3D printing~~'s use~~ for ~~in~~ assistive device technology, (2) creating an intuitive search method to navigate the library, and (3) ~~how to~~ organization approaches to optimize ~~e~~ the library ~~in an~~ accessibi~~l~~ility~~e manner~~. ~~While there are many o~~Other challenges to establishing ~~constructing~~ such a library exist, yet the potential to impact the daily lives of ~~of such a library on~~ the ~50 million Americans with a disability (one in six) could be significant and measurable~~profound and is worth pursuing~~.

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Introduction

The evolution of technology over the last century has ~~drastically~~ dramatically changed the life of the average American. The advent of cars, computers, smart phones, and the internet, to name a few, have turned scientific fiction ~~dreams~~ into a futuristic reality. ~~The same sort of~~ Similar advancements have ~~also~~ occurred simultaneously in the realm of assistive technology. ~~Things~~ Devices like cochlear implants, voice-to-text, and power wheelchairs have significantly ~~increased~~ improved the quality of life for people with disabilities. However, while these broadly-applicable advanced technologies have helped many people, ~~there are still~~ millions of Americans ~~who~~ continue to struggle with ~~simple day-to-day tasks~~ activities of daily living, like getting toothpaste on a toothbrush, holding a pen, or tying their shoes~~,~~. ~~and there has not been nearly as much~~ Limited advancement has been achieved to address these needs~~in this kind of technology~~.[1]

Almost 20% of Americans~~[2]~~ live with a disability[2], but the actual needs of ~~these~~ each individual ~~people~~ are varied and numerous, which creates a challenge for creating new assistive technology. The cost of designing a device and then setting up a factory to produce ~~it is~~ often exceeds ~~more than~~ the potential revenue and profits ~~the device would make~~, which prevents most of these devices from coming to market~~many of these helpful devices from being produced~~. ~~This~~ Thus, people are force~~s~~d ~~people to rely on~~ to navigate the small catalog of generic devices found on large online medical supply retailer sites, or what is supplied through their local occupational therapy office. While this works for certain individuals, frequently the difficulty in obtaining the adequate device or ~~the~~ an improper fit leads to device abandonment. Shortly, ~~and the person~~ individuals resort to ~~relying on~~ "duct tape" solutions ~~to~~ for their problems; solutions ~~,~~ which lack the reliability, effectiveness, and safety of engineered products.

These limitations are ~~almost~~ near impossible to overcome with traditional, centralized manufacturing methods, ~~but~~ where the ~~recent~~ advances in additive manufacturing (colloquially referred to as 3D Printing) have opened the ~~a new~~ realm of possibilities for delivering and creating new assistive technology. Additive manufacturing is the process of "creating objects from the bottom-up by adding material one cross sectional layer at a time".[3] The process begins with a digital, three-dimensional model of the object created using computer-aided design (CAD) software, and ends with an accurate physical ~~replica of that~~ model~~ printed out in real life~~.[4] The benefits of this manufacturing method include: (1) ~~is~~ the ability to handle almost any geometry, (2) low upfront investment compared to expensive tooling needed for ~~transitional~~ traditional injection molding, and (3) ~~allows the~~ flexibility for one machine to print limitless different models.[3] As stated by Cornell Engineer Hod Lipson, "for the first time in human history, complexity is free -- making something complicated takes the same amount of time, resources and skill of making something simple".[5] These benefits position additive manufacturing as an ideal manufacturing solution to deliver personalized assistive devices, because small production runs for each personalized device do not incur the costly investment in tooling or manufacturing.

Over the past thirty years, the cost of additive manufacturing has also significantly decreased, largely due to the expiration of the patents behind the technology~~ expiring~~. The patents behind fused deposition modeling (FDM), the technology used by the popular Makerbot® machines, expired in 2009. Within five years of that expiration, the cost for a low end FDM machine fell from $14,000 to $300. In February of 2014, the patents behind selective laser sintering (SLS) manufacturing expired, which may significantly ~~cut~~ reduce the costs of ~~even more accurate~~ 3D printing with improved accuracy~~applications in the near future~~.[6] These cost ~~decreases~~ reductions ~~have now made~~ make the technology accessible to private customers.[7] Further developments have led to the ~~inclusion~~ incorporation of various materials beyond plastics, which permits ~~with~~ material properties matched to ~~different~~ specific applications, further increasing the ~~array~~ broad application of additive manufacturing to medical assistive devices~~of potential uses~~.[8]

~~These more recent advances have contributed to the role for a~~Additive manufacturing has spawned and driven ~~in~~ the "Maker Movement." The Maker Movement is a growing culture defined by the desire to fabricate, design, and assemble creations with a do-it-yourself or do-it-with-others attitude. These creations often improve upon existing commercial products, serve as prototypes, or solve a specific problem. "Makers" employ various techniques to achieve their goals, ranging from computer programming, robotics, metal working, to additive manufacturing.[9] The movement is exemplified by the Maker Faire, which is held in both New York and the San Francisco Bay Area each year. In 2014, the New York and Bay area events saw over 215,000 attendees, with another 119 independently-produced Mini and Featured Maker Faires around the world.[10]

The 3D printing/additive manufacturing aspect of ~~this~~ the Maker culture ~~has already begun to manifest itself strongly on the~~ takes full advantage of crowdsourcing on the internet. ~~,~~ ~~largely through w~~Websites, such as Thingiverse (www.thingiverse.com), ~~which~~ allow~~s~~ individuals to upload their digital CAD files under the Creative Commons license for other users to download, modify, and 3D print for free.[11] This repository exists without curation and depends~~s~~ on user input for keyword-based searches. In 2017, ~~There are already over~~ more than 100,000 models have been shared on Thingiverse, which is a testament to the open and collaborative attitude of the Maker movement. Thingiverse also has functionality that connects modified models back to ~~their~~ its original design. Tracking model development and modifications provides insight to ~~This gives the users a chance to visualize~~ the design process, and trains users on strategies to incorporate design improvements~~gives other makers ideas on how to improve the models further~~. This type of iterative user design is not an entirely new concept, in fact Ford's original Model-T was sold only in one type, and users at that time created and sold do-it-yourself kits to modify them into tractors and other motor vehicles.[12] The ~~current~~ availability of 3D printing and models on Thingiverse makes iterative user design faster and ~~this a much~~ easier ~~process~~ in the modern day, and ~~it is~~ well suited for ~~adaptation~~ adoption into the medical assistive device arena. Advanced ~~U~~users ~~theoretically~~ could find an existing device that may work~~s~~ for them, modify it, and then re-upload those changes to share ~~pass those improvements on to~~ with other users.

By taking advantage of the advances in additive manufacturing and the Maker Movement, we ~~believe~~ propose ~~that it is possibly to create~~ a digital library of medical assistive devices for ~~aimed at~~ people with physical disabilities. The library collection could be comprised of CAD files for the devices, which can then be personalized, downloaded, ~~and~~ 3D printed, and assembled as needed ~~for free~~. Users would be able to search the library based on disability type, body part, age, daily activity, etc., allowing them to ~~easily~~ rapidly identify devices with potential ~~they would~~ benefit ~~from~~. The digital nature of the library would also allow for ~~quick~~ device ~~customization~~ modifications based on biometric data (finger diameter, hand width, etc.), which would ~~make these~~ customize devices ~~much more customizable~~ for improved fit than the existing technology supplied by medical supply retailers. Devices for this library could be obtained from existing open source ~~locations~~ repositories on the web, makers in the community, or potentially from college engineering courses. Both health professionals and users will be able to provide feedback on utility, durability, ease of use, recommendations for future improvement, etc. Given the increasing accessibility of 3D printers and the rising prevalence of Maker Spaces, this idea is now feasible, affordable and accessible.

This document contains three white papers discussing the key challenges in ~~making~~ creating such a library. The first discusses in more detail the viability of 3D printing as a manufacturing option for assistive technology. The second proposes a unique search feature to ensure quick and easy access to relevant devices. The final paper discusses the challenges to organizing such a library and ~~the~~ an organizational structure to accommodate the diverse collection of devices~~that could be adopted to deal with it~~. To date, no such library exists, so these documents can help guide the creation of such a library for the first time.

Methodological Approach

To research the feasibility of creating ~~this~~ a digital library of 3D printed medical assistive devices, broad searches of the literature and ~~web~~ internet were ~~done~~ conducted using Google and Google Scholar ~~and~~ with various search strategies~~a variety of keywords~~. The most relevant sites identified were Thingiverse (Thingiverse.com), GrabCAD (GrabCAD.com), Assistive Technology Solutions (ATSolutions.org) and Performance Health (PerformanceHealth.com). Thingiverse and GrabCAD are two of the leading websites that host user-uploaded 3D printable files, and the~~ir~~ websites were ~~evaluated both to examine~~ explored for the~~ir~~ user interface, indexing, and ~~as well as look at the~~ types of medical assistive ~~living~~ devices ~~uploaded~~ in ~~into~~ the~~ir~~ ~~libraries~~collections. Assistive Technology Solutions is an online, open source community that provides resources and designs for DIY assistive technology projects, and was explored to evaluate their methods for organizing assistive technology. Performance Health is a large online retailer of medical supplies, ~~and they have~~with a considerable amount of assistive technology in their catalog, but no library per se. Their catalog was ~~analyzed~~ explored for ~~to see how it was~~ structure~~d~~, ~~as well as what pre~~existing ~~technology~~ devices ~~is being~~ produced via traditional manufacturing methods, and device descriptions.

Expert opinion was ~~also utilized~~sought to develop a framework for the library ~~in our recommendations~~. We ~~had~~ held discussions with professors from the Northern Arizona University's Departments of Occupational Therapy and Physical Therapy to gain ~~their~~ perspective on their needs as providers and those of their patients~~our goals~~. We also met with University of Arizona Tech Transfer Office to help identify ~~any~~ prior existing libraries of this nature, of which they found none.

To test the process of using and modifying CAD files, an installation of SolidWorks 2016 was used with a student license obtained via the University of Arizona. CAD files were downloaded from ~~based off models found on~~ Thingiverse and modified.

Advantages of 3D Printing Compared to Traditional Manufacturing Methods to Manufacture Assistive Technology

Introduction

Currently, if someone needs assistive technology, they have a few options for obtaining them. The first is to search a large, online retailer to see whether their products meet their if they happen the have what you needs, in the size you needcorrect size. If that avenue approach fails, you could pay a visit to your local OT/PT, hoping that they might have some insight on where to find the a relevant device you need. Finally, if neither of those outlets work for you, you can settle for the least elegant of all… duct tape. Even though approximately 1 in 5 Americans are living with a disability,[2] their needs are often unmet by the availability of assistive technology. A major reason for this is that while there are many people with disabilities, their unique needs often do not add up to create enough market power for a company to overcome the large upfront costs of designing, patenting, and manufacturing, and marketing that come with creating a new device. For the devices that do exist, people often have trouble finding them, and when they do identify a device, they often struggle with an improper fitacquiring it in the size they need.

We propose that 3D printing could solve many of these problems, and serve as the future of assistive technology. It is becoming more available to the everyday user, and it eliminates many of the barriers created by traditional manufacturing. 3D printing also makes it easier for users to obtain personalized devices, allowing for a better fit than standardized one size fits all products.

The Increasing Availability of 3D Printing

Additive manufacturing, or more colloquially 3D printing, is the process of "creating objects from the bottom-up by adding material one cross sectional layer at a time".[3] The actual printing can be done in a variety of different fashionsways. Some of the common techniques include using UV radiation to selectively solidify a liquid polymer (stereolithography), using lasers to weld metallic powders into a solid form (selective laser sintering), and extruding a polymer filament through a heated nozzle (fused deposition modeling). ~~A variety of o~~Other techniques exist, some of which can accommodate ~~as well as a slew of~~ different materials~~ that are now printable~~. ~~One~~ A keystone element ~~thing in common~~ between all these techniques is the use of digital 3D computer aided design (CAD) ~~files~~ to ~~serve~~ model the design~~as a template~~.[13]

While 3D printing was first created about 30 years ago, it has become increasingly available to the public over the past decade. Currently, there are over one million desktop 3D printers across the globe, and this number is growing each year. There are over 300 companies that market 3D printers, and one can be bought for as little as $300. For those who are not interested in investing in a 3D printer of their own, 3D printers have also started showing up in local libraries, UPS stores, and dedicated makerspaces.[13-14]

Not only are printers becoming more available, but the tools to use them are also becoming easier to come by. Classically, the CAD programs were expensive to purchase and difficult to learn, but the interfaces to these have become much more user friendly, and many programs can be downloaded for free online.[16] In fact, Microsoft Windows 10 comes with 3D Builder pre-installed, and contains a catalog of child and desk toys. To ~~make things even easier~~improve use of 3D printers, sites like Thingiverse have thousands of free 3D models uploaded to their site, available to be modified or printed for free by anyone (Thingiverse.com).

With the current availability of both 3D printers and CAD, anyone can design their own model (or download one from a website like Thingiverse) and either print it themselves, or put it on a flash drive and take it to their local 3D printer. While 3D printing is not yet a known commodity for most Americans, it is currently ~~in a place where~~ positioned ~~the technology is~~ within reach for those who seek it out.

Distributive Model of Manufacturing

The key to the success of ~~this~~ the proposed library is the distributive model of manufacturing that 3D printing makes possible. In a traditional manufacturing model, a company would collect resources to a central location, construct a product, and then ship that product out to distributors for purchase and retail sale. For certain products, this is an effective strategy.[17] Having all the resources and machines in a centralized location allows for excellent quality control of the products being manufactured. It also allows for resources to be bought in bulk, therefore reducing the per unit cost of making a product. However, when only a few products are needed, this method becomes extremely inefficient. Inefficiency comes from retooling machines and setting up manufacturing processes with each new device. The ultimate profit from only a few products usually cannot justify the large upfront cost of purchasing materials, investing in the tools necessary for manufacturing, factory time/space, and distribution.[18] It is this barrier that prevents most assistive living devices from being ~~produced~~ manufactured for ~~many of the~~ rare~~r~~ ~~disabilities~~disorders and disabilities. If only 1:100,000 people are affected, the cost analysis cannot ~~n there is no way enough devices can be purchased to~~ justify the production costs of even the ~~a~~ simplest assistive living devices.

At its core, the distributive model of manufacturing differs from the traditional approach by changing an economy of scale to an economy of one. Traditional manufacturing thrives at making a high volume of simple products at a low cost. ~~, but that is not what someone with a r~~Rare disorders and disabilities ~~y needs. They~~ require ~~a~~ low volume (frequently just one), ~~of a~~ complex products to fit their unique needs. ~~In the past this was not easily achieved, but w~~With the rise of 3D printing, manufacturing one device ~~this~~ is ~~becoming much more~~ now possible~~feasible~~. Instead of making devices at a centralized location, STL files (the standard format for 3D models) can be sent anywhere in the world ~~where~~ for the ~~user~~end-user to ~~can~~ print ~~it~~ as desired. ~~Now that~~ 3D printers are becoming more accessible, both to own and to find locally, ~~this is becoming a feasible distribution method. Additionally,~~ allowing every~~any~~ printer ~~can~~ to print any device, thereby ~~which means that~~ allowing the personalization~~ing~~ or modification~~ying~~ of designs without ~~does not incur any~~ additional cost~~s~~. As summarized by Cornell Engineer Hod Lipson in an interview with CNN, “for the first time in human history complexity is free -- making something complicated takes the same amount of time, resources and skill of making something simple”.[5] In this case, complexity can be defined as the personalization of assistive living devices.

This distributed manufacturing model is ~~perfect~~ ideal for ~~the~~ a library of assistive living devices~~we are currently developing~~. ~~It allows for us to~~ All CAD files and relevant descriptors in the library ~~store and organize all the devices as STL files,~~ can be made available, without operational costs associated with ~~having to worry about~~ manufacturing ~~the~~ devices ~~ourselves and~~ or keeping an inventory. ~~This is also ideal f~~For the users, ~~as~~ they ~~will be able to~~ can download these files for free, and if they have the skills/interest, modify the devices themselves to further personalize it. Lastly, ~~It also allows for the users to get the~~ devices are manufactured on demand and onsite, thus ~~almost instantly,~~ eliminating ~~any~~ shipping costs or processing times.

Customization

~~Aside~~ In addition to the advantages of ~~from allowing~~ distributive manufacturing, 3D printing ~~also~~ offers ~~a lot of~~ capabilities ~~that suit~~particularly suited to assistive living devices ~~particularly well~~. A survey was performed by Philips and Zhou in 1993 to evaluate what factors led people to keep their assistive devices compared to ~~those~~ devices that they abandoned. ~~They found that~~ Approximately one-third ~~29.3%~~ of all assistive technology (29.3%) purchased ends up abandoned and unused. The factors ~~they found to be statistically significant to~~ that predict abandonment were: lack of user involvement in device selection, difficulty of procuring the device, poor device function, and changes in the user's functional status that rendered the device unusable.[19] 3D printing can provide direct improvements on three of these factors compared to traditional manufacturing. As stated previously, today’s availability of 3D printing allows for easy device procurement, and the number of devices in the library provide ~~many~~ options for users to find a device for themselves that ~~they like and~~ fits their needs.[20]

3D printing can also take it a step further and allow for users to personalize their devices ~~as well~~. ~~This can be done by the~~ U~~u~~sers can custom size devices, ~~themselves~~ if they have ~~some~~ literacy and experience with the technology, but ~~it~~ the process may be automated ~~can also be done automatically~~ through ~~our library using~~ the concept of global variables. A global variable is a measurement in a device that can be ~~changed~~set by the user, thereby scaling or morphing the ~~rest of the~~entire device ~~to accommodate for~~ based on those changes. While this flexibility ~~can~~ requires additional design features ~~a little more work~~ upfront ~~when designing the devices~~, ~~if~~ the scaling feature adds personalization for many users with a single digital modeling file ~~done well it can allow for one single file to be quickly modified to fit many uses~~.

Below is an example of device scaling and customization~~An example of this is shown below~~. Figure 1a depicts a pen holder designed by Shaz Hossain and uploaded to Thingiverse (www.thingiverse.com/thing:1324235) under the creative commons license.[21] According to the designer, this device is aimed at making it easier for people who have trouble with hand dexterity to hold pens. Figure 1b shows a reconstruction of that device made by this author using SolidWorks 2016 (SolidWorks.com), a CAD software provided by the institution. This image also shows what parameters we would like to have customizable, namely the hand width and pen diameter. Figure 1c shows how we were able to utilize the global variable "Hand_Width" into the sketch to alter the width of the device, and figure 1d shows the same for the global variable "Pen_Diameter." With these global variables integrated into the sketches, the device can be personalized by changing the values of those variables, which is shown in Figure 2a and 2b. From a user perspective, they will be able to go onto the site, input their biometric measurements, and within seconds have a personalized model ready for download and printing.

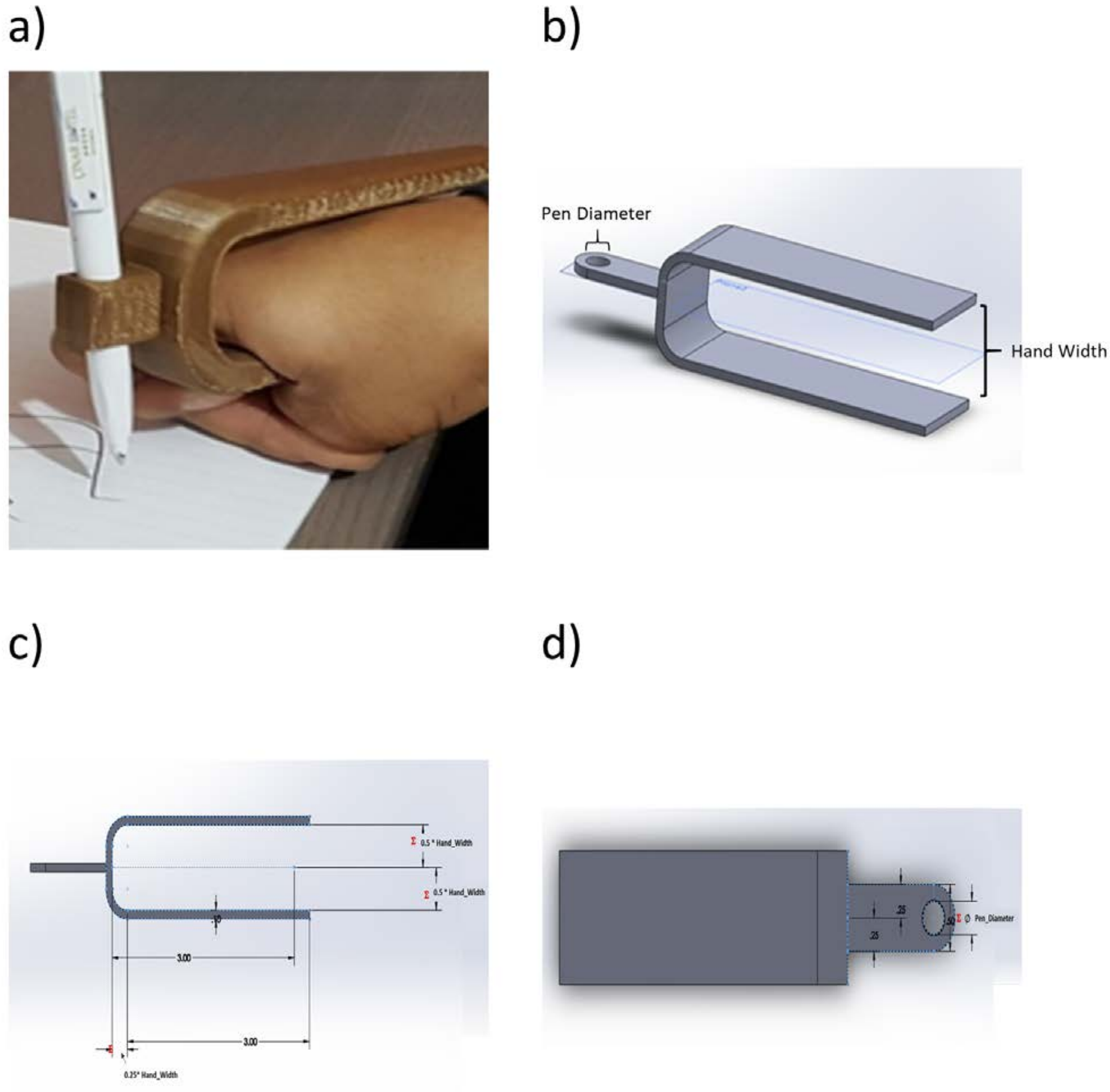

Figure 1 (A) Image showing a pen holding device designed by a Thingiverse user. (B) ~~The right is a~~A digital reconstruction created by the author ~~based upon Mr. Houssain's design~~to demonstrate the flexibility of digital modeling. (C) A sketch showing the integration of the global variable "Hand_Width" into the model. It affects both the distance between the upper and lower portions, as well as the radius of the curve. (D) A sketch showing the integration of the global variable "Pen_Diameter" into the model.

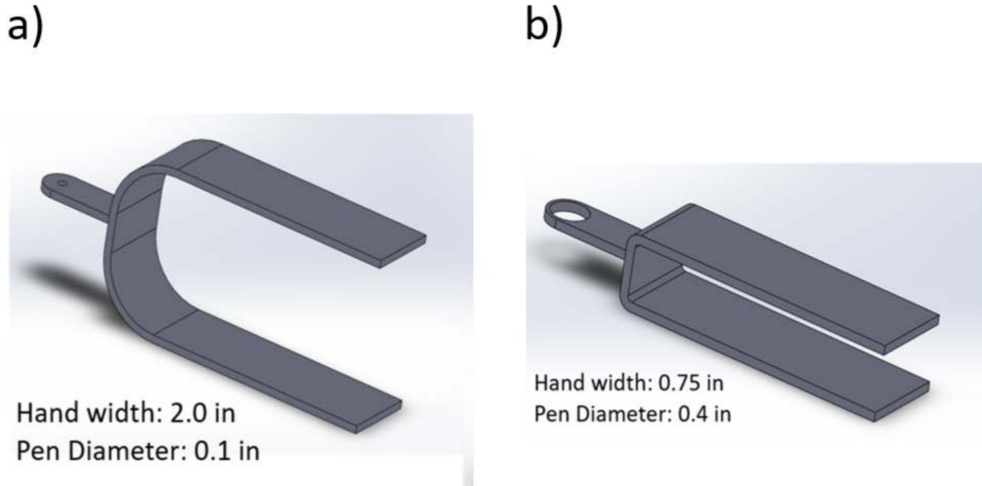

Figure 2 By changing the global variables for "Hand Width" and "Pen Diameter," the file automatically modifies itself to better fit the ~~users~~user’s needs. (A) shows a larger hand width and smaller pen diameter, while (B) shows the reverse.

Using global variables ~~like~~ in the manner illustrated ~~this will~~ allows device customization by ~~users to simply~~ input of an easy to obtain measurement (e.g. ~~like the~~ width of their hand, diameter of a finger, distance between points~~etc.~~). The output ~~and have the computer send a~~ 3D printable file ~~that~~ perfectly fits the user's needs~~their body~~. If ~~the~~ users find the fit too tight or too loose, a second attempt can occur by adjusting the values of the variables. A~~they can simply change that value and download a~~ second file with new parameters ~~almost instantly. This prevents~~ avoids the ~~problem~~ challenges of ordering a device online only to find out that it doesn't fit and a~~n entire~~ new product needs to be ~~bought~~purchased. ~~This c~~Customization could be ~~can~~ improved even ~~more~~ further by incorporating ~~with the growth of~~ 3D scanners ~~on the horizon~~. In the future, ~~a~~ users ~~will be able to~~ may 3D scan their affected body part (e.g. hand, fingers), upload ~~it~~the scan ~~to the website~~, and ~~the~~ modifications to the selected ~~device can be modified to~~ would result in a perfect fit ~~the person perfectly~~. This approach is not yet practical~~technology does exist already~~ due to limited ~~, but the~~ availability of 3D scanners ~~is poor~~ and labor intensive ~~the~~ process to integrate a 3D scan into a digital model; ~~currently to make perfect matching devices off 3D scans is more labor intensive than the almost~~ the semi-automated ~~entirely automated~~ use of global variables is immediately available.

Remix Culture of 3D Printing

~~Another~~ The ease of customizing 3D models has led to a lot collaboration within the 3D printing community. A great example of this has been achieved on Thingiverse. Currently, Thingiverse operates under the Creative Commons license, meaning that any device can be downloaded, modified, or even sold by anyone. This ~~has~~ approach has fostered ~~led to~~ a "remix" culture ~~on the website~~, where new devices can be uploaded and linked to their predecessors, showing how ~~they~~ devices change~~d~~ and ~~improved~~ evolve through an iterative ~~the~~ device process~~, and inviting other users to carry on the trend~~.[22] The crowd sourcing approach is fueled by ~~This culture stems from~~ a community with ~~a~~ creative energy ~~aimed~~ to design ~~at creating~~ cool things ~~and~~ that can assemble to make ~~making~~ the world a better place ~~while doing so~~. Without specific directive, ~~Users~~users on Thingiverse ~~have already started to~~ upload assistive technology and continue to improve ~~it~~designs.~~,~~[23] ~~and~~ A exclusive library of medical assistive devices will be successful by promoting a similar culture of crowd-sourced design improvements~~the hope is that a similar phenomenon can be cultivated into modifying and improving the free devices uploaded into our library~~. This collaboration could never realistically be achieved with traditional manufacturing, which reveals yet another benefit of the 3D printing ~~model~~approach. ~~It is an exciting future possibility though.~~

Safety Parameters

~~One~~ Device safety in the use and construction ~~concern that~~ of 3D printed devices is a concerning~~ing does bring up is the safety of the products being used~~. Each 3D printer has its own print bed, generally limiting the size of objects to ~~objects that are~~ less than a cubic~~t~~ foot. ~~This~~ Although ~~prevents any~~ large, weight bearing devices ~~from being~~cannot be printed, ~~but there still are~~ concerns remain about the strength of ~~these~~ each printed~~able~~ devices~~s~~. ~~Looking into this, a study was performed by~~ Tymrak et al. ~~in~~ (2014) ~~to~~ investigated the mechanical properties of 3D printed parts. The printers used in this study were RepRap printers, low-tier printers that are made primarily out of 3D printed parts themselves. The materials evaluated were ABS and PLA, two of the most common materials used in standard desktop FDM printers. ~~When testing~~ S~~s~~amples from these printers had~~, they found that the~~ mean tensile strengths ~~were~~ of 28.5 MPa for ABS and 56.5 MPa for PLA. In comparison, injection molded parts have ~~reports~~ tensile strengths of 34-43 MPa for ABS and 30-63 MPa for PLA.[24] ~~This implies that~~ ABS printed parts may be slightly weaker than injection molded parts, while PLA printed parts appear to be on par with injection molded parts. Therefore, ~~it is not unreasonable to have similar~~ expectations for ~~parts~~ 3D printed ~~to~~ plastic devices or parts ~~you~~ are expected to have mechanical strengths equivalent to those ~~might purchase~~ from a traditional vendor. Of course, ~~there are many different types of~~ each printer-material combination will vary~~s and many different materials that can be printed~~, ~~so~~ but this study ~~cannot~~ indicated that ~~be generalized to all printers, but~~

~~the fact that these~~ lower end printers compare favorably to industry standard injection molding, and thus ~~is reassuring that~~ functionally strong parts can be made on 3D printers.

While 3D printed parts ~~appear~~ individually may ~~to~~ have ~~inherent~~ material integrity, ~~it does not ensure that~~ the designs themselves ~~will~~ must undergo safety testing~~be functionally appropriate~~. ~~Having users upload their devices to the website allows for rapid innovation, but it does not ensure the safety of the devices.~~ To ~~do~~ convey safety standards for 3D assistive devices~~so~~, we ~~are~~ propose~~ing~~ a certification system to ~~label~~ classify ~~which~~ devices from early prototype to ~~have been tested and can be deemed~~ "reasonably safe.~~,~~" ~~while~~ Initial designs may be designated at ~~other devices are~~ "use at your own risk" (similar to the existing industry standard set by Thingiverse). ~~In order for a~~ D~~d~~evice ~~to be~~ certification may include a process outlined here.~~ed, there are a few required components.~~ First, the uploader of the device must state a clear purpose for the device (e.g.~~i.e.~~ wheelchair cup holder), so that expected forces on the device can be estimated. Then, t~~T~~he device will ~~then~~ be ~~examined~~ evaluated by an engineering ~~evaluation~~ committee to determine its ~~if it is~~ mechanical fidelity~~ly sound~~. ~~The~~ Digital models can be evaluated for simulated tensile strength and sites of failure using finite element modeling. Printed models can be evaluated for tensile strength ~~device will either be printed and tested in real life~~ on a universal testing machine~~ to evaluate the devices tensile strength, or because the devices are digital, can be tested using finite element modeling to determine the most likely sites of failure, as well as the simulated tensile strength of the device~~. Evaluation may be crowdsourced or centralized at a specific facility. From these evaluations, ~~reccomendations~~recommendations for ~~Once these measurements are obtained, the device will then be given suggested~~ print material and printer settings are assigned as metadata to the ~~digtal~~digital model in order to ~~ensure~~ establish a safety factor of at least 2.0, where ~~(meaning~~ the device will be able to withstand ~~double the~~ twice force ~~that it is~~ expected ~~to encounter~~ during routine use). While this certification cannot predict or prevent any and every type of device failure, it can set a reasonable standard for safe use.

Conclusion

With the increasing availability of 3D printing to the general public and a Maker Movement based on crowdsourcing, we believe demonstrate the that it is finally becoming feasibilitye to create of a library of 3D printable assistive living devices. Freedom from the habits of traditional manufacturing will allow provide for users with to get almost instant access to any customized devices that were previously unavailablethey want, and allow for almost infinite customization of these devices. Studies have shown that 3D printers can fabricate functionally strong parts, and with coupled with digital and failure the use of real life testing and FEM, an entire library of these devices can be available to millions of people in need of assistance with activities of daily living.tested and accompanied by printing recommendations to promote the safety of our users.

Using a Medical Avatar as a Search Tool

Introduction:

In the current digital age, ~~there exists almost~~ an unmeasurable amount of information and entertainment exists ~~out~~ in the vast landscape of the internet. To ~~reach~~ access information~~it, all we must do is conduct~~ requires a ~~simple~~ search. Whether you are searching globally ~~the entire web~~ via a search engine like Google™~~,~~ or in a restricted manner on a specific ~~doing an internal search of a~~ website, searching has become ~~synonynmous~~synonymous ~~a common part of interfacing~~ with the digital world. However, when it comes to medical information, the unwieldy terminology used by healthcare professionals ~~can make it difficult~~ is a challenge for patients unfamiliar with the language to find information or accurately express their constellation of symptoms, as in an online search. Our purpose is to construct a universal database and library of medical assistive living devices that can be 3D printed in a distributive manufacturing model (see White Paper #1). As users necessarily must search for devices, restricted to their needs, a language independent, novel interface is required. In this white paper~~To address that discrepancy~~, we ~~are~~ propose~~ing the usage of~~ a medical avatar to search health information, and specifically our database of 3D printable medical assistive living devices. ~~The usage of a~~As will be discussed, a medical avatar ~~not only will~~ eliminates medical jargon for the patient to process, electing for sign and symptom characteristics that can be ~~from the patient's side, but it also will allow for~~ grouped by ~~ing of~~ disability~~ies~~ and ~~by~~ functional status, rather than ~~instead of by~~ medical diagnosis.

Creating a Medical Avatar:

The current trends in design ~~are leading toward~~ show more and more ~~people~~ programmers ~~choosing to use~~ electing for a graphical user interface (GUI)~~ in their software~~. GUIs allow users to interface with the digital world using images and other graphical elements, rather than ~~. Instead of~~ relying solely on words or text-based commands. ~~, the g~~Graphics allow

~~the~~ users to see what they are doing~~,~~ and ~~can~~ provide feedback ~~to the user~~ during their interaction with the software.[25] Compared to text based user interfaces, studies have shown that GUIs allow for more rapid adoption and faster and easier accomplishment of digital tasks, especially for novice users.[26]

Given the complexity of the medical field, graphics and images may advance ~~seem to be an ideal way to~~ patient communicat~~e~~ion regarding health care to and from a provider, whether a person or a digital assistant ~~with patients, and a variety of studies have shown this~~. ~~One study looked at the efficacy of~~ When using a “pill card” ~~that~~ with ~~had a~~ pictures of the pill and time of day the pill should be taken, ~~. Their results showed that~~ 94% of patients ~~found~~ reported that the visual ~~aide~~aid was useful in adhering to the~~ir~~ medication schedule.[27] ~~Another study showed that providing a~~ Next, visual aids ~~when talking with patients~~ lead to higher levels of attention and better information recall during provider conversations, especially in low literacy patients.[28] Graphics have ~~even shown to~~ increased compliance rates in patients instructed to get the ~~their~~ Pneumovax vaccine.[29] Substantial information is now disseminated through infographics, which use pictures and schema to convey ideas and relationships between topics. ~~Given these and other findings, it is easy to come to the conclusion~~ It follows that using graphics/images have an important place in patient education. ~~Because of this~~In response, we ~~have~~ explore the possibility of ~~decided to~~ incorporating~~e~~ graphics into the search component of ~~our~~ a database of assistive living devices by having ~~our~~ users create medical avatars.

An avatar is a digital representation of a user created by that user. In the early days of the internet, the first avatars were simply images associated with a username and used ~~on~~ in online discussion forums. ~~However, given the advances in current technology, avatars have the ability~~ Since then, avatars have evolved to be much more complex. An example of ~~a~~ more complex avatars can be seen with ~~are~~ video game characters, ~~where~~ for which the user ~~has the opportunity to~~ changes body and facial features of the character to the point that it resembles the actual user. A prime example of the use of avatars for this purpose is the Mii, shown in Figure 3, created by Nintendo. The Mii serves as the player’s digital identity and allows the player to interact online with ~~each~~ others in various settings~~a variety of differe~~. ~~There~~ Countless other ~~are many other~~ implementations of avatars exist, and in most cases the avatars are used as a means of self-expression. The avatar represents one or more characteristics of the user. Given the relationship between user and avatar, coupled with the user familiarity with the avatar concept, we propose the We believe it is possible to use of avatars as a means of to collect and store medical data collection in a medical setting. If a patient with a disability or functional deficit impairment were able to make an avatar that looks and functions like them and has the same problems they do, then it is becomes possible to take that representation of them and "reverse engineer" it the avatar back to a medical diagnosis or a functional status. To date, we have not been able to identify an existing avatar that is able to accommodate for a user's disability or functional impairment.

Figure 3: The "Mii" is the video game company Nintendo's version of an avatar. People can make the Mii look like them ~~and then~~ for use in ~~in~~ a variety of games and other features on the gaming system.30 Functional aspects cannot be assigned to the Mio avatar.

Components of ~~Our~~ a Medical Avatar

~~The~~ A medical avatar would require the following ~~we are creating for our database will have~~ four main components:

- Visualization
- Range of motion (ROM)
- Strength
- Preset templates

~~The~~ Visualization ~~first component~~ is the actual look of the avatar itself. Most of the current avatars in use today are of people (from cartoon to realistic) without disabilities. For a medical avatar, it becomes necessary to incorporate ~~but our avatar will be designed to encompass~~ a broad range ~~large variety~~ of congenital and accidental deformities, disabilities, and functional impairments. Instead of ~~using~~ relying on a ~~large~~ database of diagnoses to be selected, ~~this will be done by creating an in-depth interface~~ patients can interact with the medical avatar ~~allowing a patient~~ to remove, change the size, or distort any body part. Therefore, if a patient has a rare congenital malformation of the upper extremities, the patient can change the arms of their avatar to represent that. Included in this interface will be common medical assistive devices such as wheelchairs, walking braces, etc., which ~~are important components to allow all~~ empower patients to more completely express themselves in their medical avatar.

Beyond physical limitations, t~~T~~he next components of the avatar are the functional measures of ROM and strength. These measurements provide ~~an~~ additional depth to the avatar, allowing for patients with ~~normal~~ typical anatomy to expression ~~that does not~~ functional impairments ~~normally to represent themselves~~. The measures of strength can be localized simply to each extremity, or in more detail by spinal level. ~~The~~ Optimal measures~~ment~~ of strength ~~itself will be based on~~ would be the actual weight that the patient can lift, rather than the medical “5/5” scale. Range of motion ~~can~~ could be captured by a slider in both the positive and negative directions from rest, where users can visualize their own movement while adjusting parameter for the medical avatar. Moving the sliders will correlate with movement in the avatar~~, so the patient can tweak the ROM until it matches their own~~.

~~The~~ The greater functionality (or dysfunction) programmed into the medical ~~goal of this~~ avatar, the larger proportion of the disabled population that can be represented. ~~is to have as much functionality as possible so as to include as many different disabilities as possible. This~~ Endless possibilities in medical avatar customization would ~~will theoretically~~ allow a user to accurately portray their body and its functions. Full customization likely would require ~~spend~~ a significant amount of time ~~tweaking their avatar until it is almost an exact representation of themselves~~. ~~However~~To this end, certain select disabilities/profiles need to be available as a preset template avatar, especially to include ~~there are~~ disabilities ~~that have~~ with a ~~much~~ higher prevalence ~~than others, so instead of requiring every single person with that "common" disability to create an avatar from scratch, certain select disabilities/profiles will come with a preset avatar~~. ~~That~~ Preset templates would require fewer ~~way, the patient only needs to make some moderate~~ changes and adjustments to the ~~parameters of the~~ avatar for it to represent the user. ~~themselves.~~ By accelerating the customization time, users remain engaged and may improve adoption of this approach to storing and sharing medical information. ~~This will cut down on the time required for many people to make their avatar and allowing users to progress more quickly to the devices and minimize user fall off.~~

Using the Avatar

The medical avatar has many potential applications. Because it inherently stores personal medical information, it could be utilized in ER and primary care settings as an alternative or adjuvant to filling out medical history paperwork. It could also interface with electronic health records (EHR), allowing users to use the avatar as a personal file of their medical information that can be uploaded to the EHR when they enter a medical facility and download it again when they leave with any updated medical information. The fact that the avatar can change over time can also make it useful for a variety of rehabilitation settings, where a provider can visualize a patient's improvements over time via the avatar. The avatar can also be used to search a database for medical information or products that relate to the user. This is how our database of 3D printable medical devices plans to use the medical avatar.

Once the user creates their avatar, the characteristics that they gave their avatar will be extracted to create search results relevant to the user. If a person creates an avatar with hand weakness, then only devices geared towards hand weakness will show up. Once the user has the initial list of devices, the patient will further be able to sort the results by selecting activity types (i.e. cooking, outdoor activities, hygiene). At that point, the user will have found all devices on interest that are currently in the database.

The avatar search will not be just a one-time event, however. The users will be able to link their avatars with their site account, ensuring that it is there for any subsequent visits to the site. With the avatar permanently linked to their account, the users can sign up to receive optional notifications for any new devices that fit the needs of their avatar as the library continues to grow. For example, if the user's strength increases because of physical therapy, the user will be able to update that characteristic of their avatar and look for new devices that might require more strength to use. Conversely, if the functional status of the user deteriorates, then that can be accommodated as well.

The Medical Avatar as a Search Tool vs Traditional Text Based Search

Using a medical avatar for search has many advantages compared to traditional text-based search. The first is that it allows the users to more accurately provide healthcare information without ~~an actual patient-provider interaction~~specific knowledge of symptom and disease terminology. For example, if the user uses a traditional search term like "right anterior cerebral artery stroke," then there are multiple levels that the data can be misinterpreted. One is in the actual diagnosis provided by the user. One study reported that only 41.9% of patients could accurately state their diagnosis upon discharge.[31] Therefore, if the database requires a medical diagnosis, there is a significant possibility that the patient will not provide the "best" or most accurate diagnosis to describe their condition. The medical avatar is amenable to represent signs and symptoms, across systems, that currently affect the patient, and therefore does not rely on a specific diagnosis or ICD 10 code.

Another downfall of the traditional text based search is the level of detail required in the text field. If the user were to instead input simply “stroke,” then they would be flooded with devices that are not relevant to their specific condition, since strokes have a variety of presentations. If the user were to input a phrase like “right anterior cerebral artery ischemic stroke with ankle flexor weakness,” it might be more accurate, but the search string is too long for a conventional search engine to use effectively. Therefore, it can be difficult to get accurate results based solely on text input.

A final limitation to a text based search is that it is limited to the list of diagnoses entered into the database by the creators. It is highly possible that some rare congenital malformation is not entered into the database, but the actual functional deficits of that malformation could be solved by a device in the database. Therefore, if you searched using that term you would get no results, although that person could be helped.

Discussion:

Using a medical avatar can address many of the problems we face today when handling medical information and terminology. First, it ensures that the user is able provide an accurate representation of their health and functional status. Even if the patient does not remember their diagnosis, they know what they themselves look like and what they can do. The avatar also addresses the fact that there are many different manifestations of common disabilities. Instead of adding on a plethora of descriptive terms to a diagnosis, the avatar simply addresses the functional deficits of the patient. Because the data collected from the avatar is about the patient’s functional abilities, it also helps to accommodate patients with the rarest disabilities. If the patient is able to represent their disability via the avatar, it does not matter how rare the actual diagnosis they have is.

There are some challenges that come along with creating a medical avatar. The first is that it requires more programming and designing than a normal text based search engine. The avatar builder must be made to accommodate for a wide range of disabilities, and the search engine must be able to extrapolate the important information from the avatar without any keywords. Additionally, it puts more of a burden upfront on the user, as making a personal avatar may take longer than filling out a form or doing a simple text search. If the avatar creator is too cumbersome or takes too long, then it is possible that users will just quit and abandon the avatar. Therefore, it is important that ease and time of use are two of the top priorities in designing the avatar.

In conclusion, we ~~believe~~ contend that a medical avatar represents a terminology independent approach to improve patient medical history, and likely comprehensive data collection. For our purposes in particular, a medical avatar is a superior approach ~~that the best way for users~~ to search a~~our~~ database of assistive living devices, ~~is with an avatar they create to represent their disability~~as an avatar would benefit from digital assistive devices in the same manner that the user can benefit from the 3D printed devices. The avatar ~~will be able to~~ can capture ~~any changes in~~ anatom~~y~~ical features associated with ~~their~~ disability, coupled with ~~as well as any of the~~ functional ~~deficits~~ impairments~~they are challenged with~~. The translational benefits of ~~using~~ a medical avatar to collect health care information ~~from users~~ are ~~that it~~ (1) eliminat~~es~~ion of complicated medical vernacular, (2) accounting for~~s~~ ~~for the~~ variable presentations of the same disease~~many~~ /disabilit~~ies~~y, and (3) ~~does not constrict the~~ open database format beyond a limited set ~~to a discrete number~~ of diagnoses. Forward looking, ~~If this is implemented successfully,~~ the ~~usage of~~ medical avatar~~s~~ could extend beyond a search tool into ~~and perhaps be used in~~ a primary care setting for triage and follow-up purposes~~, or to collect patient health data for other research purposes~~.

Proposing a new taxonomy to describe medical assistive living devices that combines medical diagnosis/disability and activity type

Intro

While the laws of thermodynamics show us that the universe is set to ~~always~~ increase ~~it~~ entropy, mankind seems set upon defying that notion. As society has evolved, we have constantly and impulsively labeled and categorized everything we come across, and use this organization to navigate the complexity of modern life. Much of the success of modern companies comes from their ability to organize things in an intuitive manner. The success of Amazon.com ~~is not only successful because of~~ comes from its ~~variety~~ range of items and~~, but because of how easy it is~~ the organizational structure to find what you need. ~~The same can be said of other websites and stores, if you are unable to find what you need, you are unlikely to continue using their platform.~~ Our team is proposing to develop a digital library of medical assistive living devices, which will necessitate ~~As there are no libraries existing like the one we are developing, it is important that we come up with~~ an intuitive organizational structure that ~~will make it easy for our~~ facilitates users ~~to~~ finding devices best suited for their ~~what they~~ needs. ~~There~~ With ~~are~~ a considerable number of different disabilities served by ~~that may benefit from the~~ countless 3D printed devices in our library, ~~and because we are utilizing 3D printing as our means to distribute the devices to our users, there are an almost infinite number of potential devices that can be made and uploaded to the system. This creates an additional challenge, as it is impossible to predict all the different types of devices that will be uploaded, so~~ the organizational structure of the library must be flexible ~~enough~~ to accommodate for disability and device combinations not yet known~~almost anything~~.

Definition of Disability

In order to create a classification system that encompasses both disability and medical devices, it is important to understand the history and definition of “disability” itself. Classically, disability was ~~often~~ described either through a medical or social ~~via one of two~~ conceptual model~~s: the medical model, or the social model~~. The medical model of disability focuses on disability as a feature of a person, caused by a disease, that ultimately needs medical treatment for improvement or correction~~to improve/correct~~. In contrast, ~~to that is~~ the social model of disability ~~, which~~ attributes the functional limitations not to the person, but rather a society that ~~has chosen to not implement~~ elected to ignore ~~all the~~ technological advances and ~~/~~resources necessary for the individual to ~~to allow them to~~ live a “normal” life, ~~and~~ thereby focus~~es~~ing on the need for political action to improve the social ~~environment~~commitment to individuals. Both models have their flaws.[33] The medical model ~~is often critiqued because it seems to~~ impl~~y~~ies that people with disabilities are “broken” and need to be “fixed.” The social model ~~is also deemed inadequate as it~~ entirely ignores an individual's condition, and there are cases where medical intervention can improve a person’s ability to function in society. As neither model can fully characterize ~~what~~ disability ~~truly is~~, a combined medical and social model ~~is not frequently described which~~ can account for ~~both~~ a person’s medical needs as well as their experience/interaction with society.[34]

In the United States, the legal definition of disability has also undergone ~~many changes~~revision throughout the years.[35] In the 1970s, disability was defined as a chronic condition that limited the person’s ability to work, and was mainly ~~utilized~~ used to identify people who could benefit from vocational rehabilitation. Moving forward, this definition was broadened to include a condition that impairs a person from completing any major life activity, a definition proposed by the Rehabilitation Act of 1973. In 1986, the National Council on the Handicapped (now the National Council on the Disabled;~~, or~~ NCD) proposed to Congress the need for a comprehensive equal opportunity law, which ultimately birthed the Americans with Disability Act (ADA) in 1990.[36] ~~The~~ Amendments to the ADA ~~has since undergone a variety of amendments, one particularly important one being~~ include the ADA Amendments Act of 2008, which gives us the current *legal* definition of disability. ~~Currently~~Today, the ADA defines a person with a disability as someone who (1) has a physical or mental impairment that substantially limits one or more "major life activities," (2) has a record of such an impairment, or (3) is regarded as having such an impairment. However, other organizations, ~~this is just one~~

~~definition of many.~~ such as ~~S~~social security, state vocational rehabilitation offices, and many other institutions, have ~~created their own definitions of~~defined disability to serve their needs.

To ~~create~~ establish an organizational structure for medical assistive living devices~~our library~~, ~~it is not essential for us to rely on one specific~~ a single definition of disability is not essential. Rather, ~~As an open source library, our goal is not to create a new definition of disability, but rather to create~~ a robust yet flexible organizational structure ~~that can~~ needs to accommodate ~~the~~ different definitions of disability in a way that ~~fits~~ includes ~~the needs of our~~ all who self-identify with a disability~~users~~. To ~~do so~~be successful, ~~it is important that we are able to identify~~ users with specific disabilities need to be connected with ~~the type of people who can get the most use out of our library, identify the types of~~ medical assistive living devices tailored to their needs, where the organization structure inherently links these elements. ~~that are appropriate for our library, and to connect those together.~~

Requirements for ~~Our~~ a Medical Assistive Living Device Database

The medical assistive living devices in our library are stored as 3D printable files. ~~This allows for~~T~~ t~~he files to be accessed anywhere ~~there~~ through ~~is~~ a connection to the ~~an~~ internet ~~connection~~, and ~~to be~~ printed by anyone with access to ~~a wide variety of different~~ a 3D printer~~s~~. While almost any geometry can be 3D printed, there are limitations to the technology currently, and these limitations partially dictate the types of devices ~~we can include in our~~ suitable for the library (see Chapter 2).

The technical specifications for the 3D printer itself set the first ~~set of~~ limitation~~s~~. ~~are the technical specifications of the 3D printer, which can be illustrated by reviewing one of the most common desktop 3D printers,~~ For example, the MakerBot Replicator+ is one of thet~~ eh~~ most common desktop 3D printers, manufactured by~~.~~ MakerBot~~ is a leader in the field of desktop 3D printers, and the Replicator+ is their current flagship 3D printer~~. ~~According to t~~The technical specifications ~~they~~ report a~~, the~~ printable area of~~is~~ 29.5 cm x 19.5 cm x 16.5 cm, with ~~it can print in~~ layers as thin as 0.1 mm~~,~~ and ~~has~~ a nozzle width of 0.4 mm. The~~i~~se parameters limit~~s~~ the size and detail of the ~~possible~~ printable devices~~ accordingly~~.[37] While ~~there are~~ some printers ~~that~~ can print metals or ceramics, their availability to the public is limited~~se printers are not readily available to the public,~~. Thus, a second limitation is restricting ~~so currently the~~ devices ~~will likely be limited~~ to those produced by plastic fused deposition modeling (FDM) printers. Third, 3D printers cannot ~~also do not have any inherent ability to~~ add electrical components without user assembly, thereby restricting devices to those that ~~so the devices mainly~~ serve mechanical purposes.

Given these limitations, the focus for a library of medical assistive living devices ~~of our library~~ narrows ~~significantly~~ from the broad umbrella definitions of disability. Rather than all disabilities, we ~~are mainly~~first focus~~ed~~ on disabilities that can be improved with smaller, mechanical devices. The material limitation ~~(having~~ to ~~use~~ plastics~~) also~~ restricts ~~our~~ devices from being used in ~~any~~ high force situations. Exceptions likely exist, where ~~It is possible that~~ devices from ~~our~~ the library could ~~be useful for~~ benefit people with non-mechanical disabilities, such as visual or hearing impairment, but likely to a lesser extent.

Existing Taxonomies

To ~~create~~ develop a flexible ~~our~~ taxonomy for medical assistive living devices, first we ~~first analyzed some of~~ evaluate the ~~currently~~ existing organizational systems employed by organizations to classify disability.

International Classification of Functioning, Disability, and Health (ICF)[38]

The World Health Organization has developed ~~One existing classification system that is particularly thorough is~~ the International Classification of Functioning, Disability, and Health (ICF) classification system~~, created by the World Health Organization~~. For this system, ~~They use the term~~ "disability" is used as an umbrella term for impairments, activity limitations, and participation restrictions, and the way both personal and environmental factors interact with those. Figure 4 shows a visual representation of the ICF model for ~~disabilty~~disability, ~~as well as~~ and an example of how their model is used. The main components used in this system to describe a disability ~~are~~include: body functions and/or structures, activities and participation, and environment. Each of these components has subheadings and further details, leading to ~~the~~ a global description of the ~~ability to describe a~~ disability ~~in a detailed fashion~~.

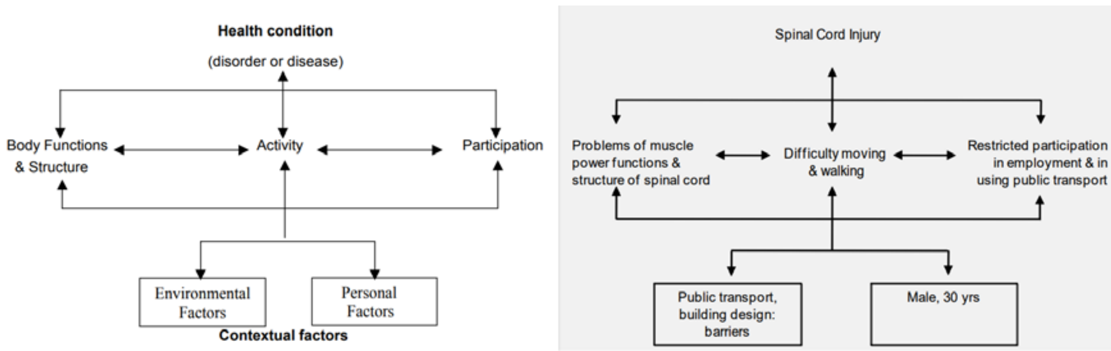

Figure 4. ~~Left shows t~~The generic ICF model for disability (left). ~~The right shows a~~An example implementation of ~~this~~ the ICF model for spinal cord injury (right).[38]

~~One of the strengths of this~~The ICF classification system ~~is that it~~ is not tied to any medical diagnoses or even specific disabilities. Compared to the ADA definition, which serves to put a “disabled” label on a person for the purposes of protecting a person’s civil rights, or qualifying them for additional resources, this definition is purely based on describing the actual functional limitation. Functional limitations can be improved with mechanical assistive living devices. For the proposed library, the ICF classification system can link ~~This is ideal for a library like ours, as it allows us to classify devices in a way that is accessible to~~ users with a specific functional need to devices classified for the functional purpose~~, rather than users with a specific diagnosis~~.

While robust in describing disabilities, ~~there are a few~~ shortcomings of ~~this~~ the ICF classification system exist when applied to ~~when it comes to classifying~~ medical assistive living devices. ~~This~~ Since the classification ~~is meant to~~ characterizes disability, rather than ~~and because of that it does not delve into~~ specific activities of daily living, such as ~~actions like~~ brushing your teeth, combing hair, etc. ~~It remains to be seen what type of volume the library will ultimately attain, but having~~ A more complete user experience would include descriptive terminology for activities of daily living, beyond ~~actions can more appropriately divide devices, compared to just~~ listing “toileting” or “dressing.” ~~Another shortcoming is that~~ Secondly, even though the classification system focuses on functional outcomes, and ~~even goes into~~ provides great detail on some outcomes such as muscle function~~of them~~ (e.g. ~~take a look at the Muscle Functions section:~~ b730 Muscle power functions, b735 Muscle tone functions, b740 Muscle endurance functions, b749 Muscle functions, other specified and unspecified), it does not fully characterize ~~these~~ functions in a way that ~~fully~~ describes the ~~deficit~~impairment. A problem with muscle tone could be either muscle spasticity~~,~~ or lack of muscle tone. Muscle power function could range from complete paralysis of the limb~~,~~ to weakness, or even amputation of said limb. While these details may not be needed when creating a general disability classification system, the details are essential to ~~do play an important role in what type of~~ the devices needed to compensate for an impairment~~should be used to intervene~~.

Overall the ICF is a detailed and robust classification system that lacks ~~some~~ detail to ~~of the descriptive functions needed to sort~~ link a person-specific disability to ~~a person to~~ a specific device.

Performance Health Catalog[39]

Performance Health (previously Patterson Medical) is a large online supplier of both medical and assistive living devices. These devices range from simple mechanical devices (e.g ~~like a~~ straw holder)~~,~~ to more advanced devices (e.g. ~~like~~ treadmills, wheelchairs~~, etc~~). To market these devices, the company has implemented a ~~One of the strengths of this~~ categorization system with ~~is that they have~~ clear and specific subheadings. If ~~someone~~ a consumer needs a ~~is looking for a~~ specialized cup, then appropriate products can be found under the following heading and subheadings: ~~they can easily find one by clicking on~~ “Dining~~,~~” >> ~~and then the subheading~~ “Cups and Drinking Aids.~~,~~” Specialized cups can be further filtered from ~~where they can find a variety of different specialized cup types from~~ “Dysphagia Cups” to “Spill proof Cups”, as presented ~~and so forth, as seen~~ in Figure 5 below. One weakness of this system ~~of the problems with this system, however,~~ is that the headings are neither mutually exclusive nor collectively exhaustive. A ~~, so you may not be able to find a~~ general heading may not exist to guide the user to the device of interest, which then ~~lead you to what you want, or you may need to~~ requires manual review of ~~check~~ multiple different tabs to find the appropriate subheading ~~you need~~. ~~Having~~ Balancing a manageable ~~the appropriate~~ number of headings and subheadings is a challenge with a large, broad catalog of devices, and will present a similar challenge for a library of 3D printed devices. ~~is quite difficult when your catalog is as broad as their list, so given the more focused products in our library we should be able to have more focused headings.~~

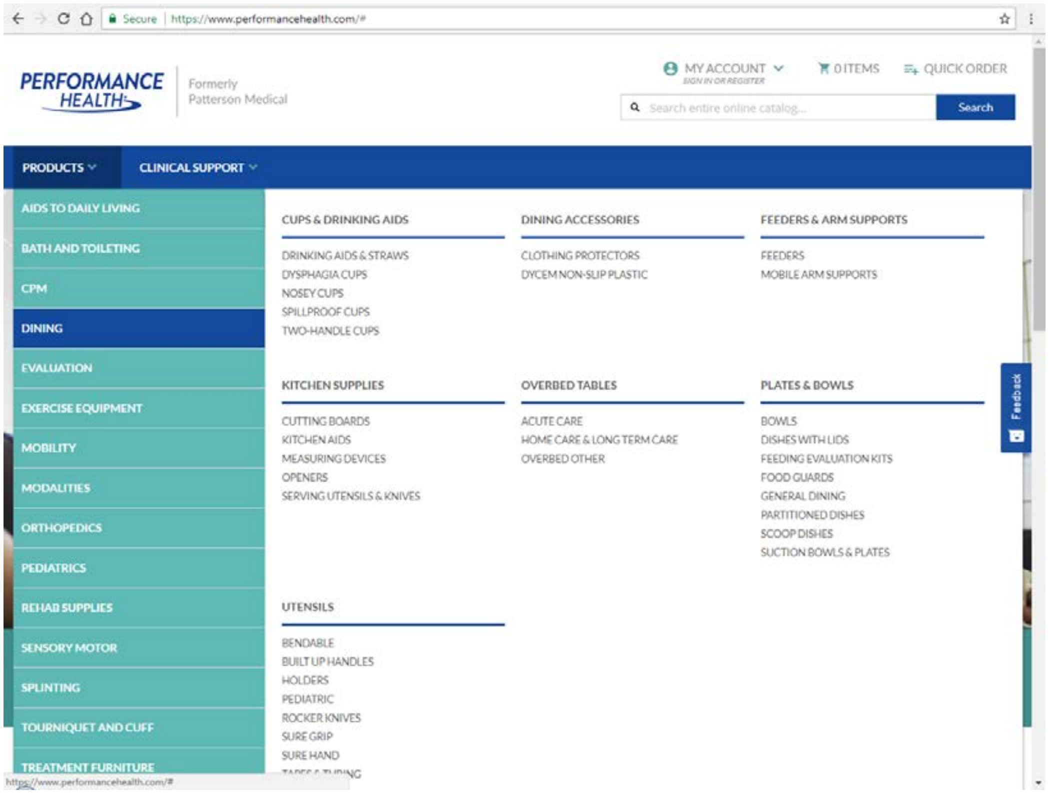

Figure 5 Example of Performance Health's device catalog. Date accessed: 1/15/2018

Our PropositionA FelxibleFlexible Taxonomy for Functional Impairment and Assistive Living Devices

The We propose a purpose-built taxonomy we chose to encompass the functional impairments of those with disabilities and medical assistive living devices designed to empower those individualsto fit our library has multiple components to it. Rather than Instead of having a single taxonomical tree, we intend to have two separate, interconnecting trees that interconnectare necessary. The first tree represents the user, their disability(ies), and functional impairmentsis based on the data gained from the avatar. Data for each user (e.g. is extracted from a medicalthe avatar) are categorized , it is first sorted into by body part and contain details regarding The avatar also collects data on the patient's strength, sensation, and ROM, which further can differentiate the devices shown. To this end, each Therefore, when a device is uploaded available into the library will receive a tag have attributes relevant that relates to the associated body part it interacts with or to and the functional deficit impairment it is designed to correctaimed at. As all of our users may not be using the avatar, and because some devices might not fit perfectly into this classification system, these tags will be an optional field. However, if the user does choose to use the avatar, this will help make their search results more relevant. Additionally, if the user saves their avatar into our library, they will have the option to be notified when new devices that would fit their avatar get uploaded to the library.

The second component tree of the library is the functional device breakdown into two layers. These will be placed in a two layer system. The first layer main headings are is loosely based on the activities of daily living (e.g. grooming, eating, transport, dressing, communicating), and the subheadings second layer provides more detail about the specific types of devices (e.g. eating -> utensils, cooking devices, dinnerware, etc.). Having a two-layer system will allows users to easily navigate towards the type of relevant devices they are looking for without being too restrictive.

Moving forward, flexibility of the taxonomy is crucial to overall functionality. one of the most important components to making this taxonomy functional is flexibility. The majority of these devices will be uploaded by users in the community, so it is important that the library can accommodate for whatever is uploaded. Uploaders to the library will be able to place their device into the trees where it fits, and/or suggest new branches for the trees that will fit their device more accurately. Downloaders will also be able to suggest new branches to help better organize the library. With all the community contributing to the classification of devices, the library will organize itself to serve the community's needs.

Conclusion

The definition of disability is always evolving, ~~and~~ because ~~as~~ society, politics, and technology continue to evolve~~, so will its definition continue to change~~. For a library of medical assistive devices~~our library~~, it is important to create a flexible taxonomy to organize ~~our~~ devices in a user-friendly manner. With inspiration from classification systems like the ICF, we have constructed a baseline taxonomy consisting of two ~~prongs~~trees: one anatomical and one functional. With this classification system, users can search or browse for devices to improve their activities of daily living by anatomical disability or functional need, where each device is tagged and queried regardless of the search strategy.~~we will be able to utilize valuable information from our users' avatars, and make it easy for them to both search and browse our library for useful devices.~~ ~~As~~ The inherent flexibility of the taxonomy allows the library ~~library continue~~ to grow~~, so will the taxonomy~~, primarily through user engagement in device development, refinement, and classification. ~~incorporating user feedback to further classify and organize the devices.~~

Discussion

Based on our ~~findings~~research, we ~~believe~~ present the framework ~~that it is feasible~~ to create an online library of 3D printable assistive living devices. Before the widespread availability of 3D printing, a system like this ~~could only be the product of~~was science fiction, but today, ~~this is a real possibility~~possibility reality. Additionally, while the technology behind this library is state-of-the-art, the actual user experience is ~~quite~~ intended to be simple. ~~They~~ Users can ~~simply~~ search for a device using a ~~personalized~~ medical avatar, enter ~~some~~ personal parameters to customize the device, and then ~~click~~ download designs for printing devices!

This library follows the trend of modern medicine to move more towards personalized medicine, which has seen great success in the recent past. Those medical models (mostly using genomics to dictate pharmaceutical choices) use information about the individual to ~~decide~~ identify the optimal ~~which of the existing~~ treatment modality~~ies is best~~. This project takes healthcare a step further. It takes patient information (their disability, anatomical dimensions, etc.) and creates a truly personalized device to fit their specific need. Given that there are ~50 million individuals in America living with a disability, the potential ~~effects~~ impact of this library could be quite profound.

Future Direction

The next direction for this research is to bring this idea to reality by creating the actual library. Key features such as device personalization using global variables, device testing and validation, creating a medical avatar, and the organizational structure are all outlined in this document. With these guidelines and recommendations, a team experienced with software development could feasibly create all the components of this library~~ to get it running~~. The main technical challenges this team will likely face are creating the avatar within the confines of HTML5 so that it can be used as a search tool, as well as finding a way for the website to communicate with a CAD program to modify the global variables and export the personalized STL files.

After the library is developed, the next step will be to begin filling the library with actual devices. This process can be started by looking through the devices on websites such as Thingiverse and GrabCAD. The devices on these sites are uploaded under the Creative Commons license, so they are free to use for any purpose. In addition to these sites, some engineering schools publish repositories of their freshman design course projects; a sustainable source for new designs~~, so more devices might be obtained from there~~. Formal partnerships with engineering schools could also be pursued to create a stream of new devices. As the library gains momentum and public attention, it is hopeful that the Maker Movement will provide some of the new devices as well.

Another hurdle ~~to cross is the funding to keep the library running~~is sustainability. It is the authors' beliefs that for this library to be successful, it is integral to keep the devices free to download. The user must already pay for the 3D printing itself, and while estimates for these costs are low, the costs would ~~really start to ~~add up if the user had to pay for both downloading and printing the devices. Keeping the devices free also allows for makers and other designers to download and modify the files without ~~any ~~additional barriers, improving the quality of the library overtime. Some thoughts about potential sources of revenue are advertising~~s~~, sponsorship deals with companies to print their logos on the devices, and charitable donations or grants from interested societies/organizations. A crowd funding source could ~~also be utilized to~~ generate the initial revenue to build the website itself.

During the implementation of this library, there will likely be many hurdles that require further innovation ~~to overcome~~, so a flexible mindset must be held during its creation. As the technology continues to grow, ~~this will also likely lead to~~ other features ~~that~~ can be ~~implemented~~ <u>incorporated</u> to improve the library. There are already technologies like 3D scanners and programs that can reconstruct a 3D model from 2D images, and in the future this technology may be utilized to further personalize these devices. Also, as the availability of metal and other 3D printing materials increase, the devices will be able to advance past the limitations currently set by the plastic 3D printers which currently dominate the landscape.

Conclusion

With the recent affordability and accessibility of 3D printing, projects like this finally can be implemented. The authors believe that a library such as the one described in this document can help improve the activities of daily living and welfare daily function of many millions of people throughout the worldconstrained by disability. While there are still many challenges to bring the first library of its kind to life, we think it is athe challenge worth undertaking.

Appendix A – Proposed Taxonomy/Organizational Structure for Devices

Anatomic Organization

- Head and neck
    - Eyes
        - Visual Impairment Devices
        - Vision Loss
    - Ears
        - Hearing Impairment
        - Hearing Loss
        - Ear Deformity
    - Nose
        - Anosmia
        - Nose Deformity
    - Mouth
        - Taste Impairment
        - Tongue Dysfunction
        - Dysphagia
    - Face
        - Facial Injury
    - Neck
        - Cervical Spine disease
        - Kyphosis
        - Lordosis
- Digestive and Urinary System
    - Mouth
        - Taste Impairment
        - Tongue Dysfunction
        - Dysphagia
    - Stomach
        -

- Ostomy
  - Ostomy care devices
- Urinating
  - Catheter care
  - Urination Devices (male)
  - Urination Devices (female)
  - Urinary Incontinence
- Bowel Movements
  - Fecal Incontinence
  - Rectal Care Devices

- Upper Extremity
  - Shoulder
    - Decreased shoulder ROM
    - Shoulder weakness
  - Upper Arm + Elbow
    - Bicep Weakness
    - Triceps Weakness
    - Elbow Stiffness
  - Forearm + Wrist
    - Pronation Weakness
    - Supination Weakness
    - Wrist Stiffness
  - Hand
    - Hand Numbness
    - Grip Weakness
    - Fine Motor Difficulty
    - Hand Deformity
    - Tremor

- Torso
    - Chest
    - Abdomen
    - Pelvis
- Lower Extremity
    - Hip
        - Hip Stiffness
        - Hip Flexion
        - Hip Extension
        - Hip Abduction
        - Hip Adduction
    - Thigh + Knee
        - Knee Flexion
        - Knee Extension
        - Knee Stiffness
    - Calf + Ankle + Foot
        - Dorsiflexion Weakness
        - Plantarflexion Weakness
        - Ankle Stiffness
        - Foot sensory loss
        - Foot wound care
        - Foot Deformity
- Assistive Mobility
    - Cane
    - Walker
    - Wheelchair
    - Brace

Functional Organization

- Personal Hygiene
    - Brushing Hair
    - Shaving
    - Brushing Teeth
    - Showering/Bathing
    - Toileting
- Dressing
    - Shirts
    - Pants
    - Shoes
    - Hats
- Eating
    - Cups
    - Plates and Bowls
    - Utensils
    - Kitchen Supplies
    - Appliance Modifications
- Home and Office
- Mobility
    - Car adaptations
    - Walker adaptations
    - Wheelchair adaptations
    - Baskets/Trays

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Intro

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