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Designing for Disability: Making Activities of Daily Living more Manageable through 3D Printing

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ABSTRACT

While there have been many innovations developed for those with physical disabilities in recent years, a multitude of unmet needs still remain. This review seeks to highlight designs, public policies, and other initiatives that have been established to assist this population thus far. Information has been curated from databases including, but not limited to, Pubmed and Policymap.

With the advent of new and affordable technologies such as 3D printing, it is now more possible than ever before to bring one's ideas to life; from creating customized prosthetics to wheelchair attachments for water bottles and umbrellas, we are able to quickly realize potentials otherwise unlikely - and in turn, we have the capacity to make the activities of daily living more manageable for those with physical disabilities. In accordance with the principles of appreciative inquiry, first-hand discussions with those having physical disabilities have allowed for some insight into the current challenges they face. Their stories have inspired the following proposed design(s) presented in this review, some of which can be 3D printed, with the hope that these developments can help them navigate the world we live in just a little bit easier.

INTRODUCTION

The Centers for Disease Control and Prevention (CDC) defines *physical disability* as a multifaceted experience, in which impairments impose difficulty for the individual to engage in activities or interact with their environment (Centers for Disease Control and Prevention [CDC], 2020). Generally, we understand physical disabilities to place limitations on one's physical functioning, mobility, dexterity or stamina (CDC, 2020). Consequently, these restrictions hinder a variety of facets of daily living. Physical disabilities may be related to congenital conditions, could potentially arise from a chronic illness such as diabetes, or result from injuries or trauma sustained at any point in one's life. Furthermore, physical disabilities can be static as in circumstances where a limb is lost, progressive such as with muscular dystrophy, intermittently experienced, (CDC, 2020) or even not-apparent (Department of Homeland Security, 2013).

This broad term thus encompasses a wide variety of conditions including, but not limited to, multiple sclerosis, epilepsy, stroke, spinal cord injuries, and amputation (Achieve Australia, 2019; Department of Homeland Security, 2013). This diversity within the realm of physical disabilities is further compounded by the diversity of those individuals experiencing them; and each person has an even more diverse range of needs. Each individual experiences a unique set of challenges intertwined with their physical disability, ranging from limited financial resources or a lack of health insurance, to certain cultural stigmas behind having a physical disability, for example. All in all, it is important to recognize that two people with the same diagnosis of a disability can be impacted in very different ways (CDC, 2020), and hence, no two situations can be equated.

However, in an effort to standardize some elements of physical disabilities, the World Health Organization (WHO) published the International Classification of Functioning, Disability and Health (ICF) in 2001 (CDC, 2020). This document “provides a standard language for classifying body function and structure, activity, participation levels, and conditions in our environment that influence our health” (CDC, 2020). Consequently, it determines factors in our society that either support or create barriers for people with physical disabilities to fully participate in activities of daily living. Once the factors that impose difficulty are recognized, accommodations can be provided so that this demographic can equitably participate in our communities. Now, with rapid advancements in technology - especially in regards to 3D printing - accommodations can be not only provided, but *created*, easier than ever before. The design process is not confined to scientists in laboratories any longer and can instead be affordably pursued by students in hackathons, hobbyists and even people with physical disabilities alike, all from the comfort of their homes.

BACKGROUND

The Prevalence of Disabilities in Our Communities

PolicyMap, an online database primarily sourced from the US census, provides curated geographical information about our communities in regards to both general categories like age and sex, as well as more specific characteristics such as homelessness and religion. PolicyMap has the ability to describe our population of disabled individuals at the national, county and city levels; in fact, it can even provide detail per zip code. The system is also able to illustrate where, and how many, of our persons with disabilities are employed, are in poverty, are veterans in poverty, receive financial assistance, so on and so forth.

While PolicyMap does not specifically express whether their data is in regards to *physical* disabilities, it still provides a necessary perspective. Of note, the system reports that between the years 2010 - 2014, persons with disabilities constituted 15.63% of the city of Philadelphia's population, whereas 12.25% of the national population were individuals with a disability. More recently, between 2015 - 2019, Philadelphia's population of persons with disabilities has risen to 16.7%. Comparatively, the national percentage has increased only slightly, to 12.62% (PolicyMap, 2021). These increasing trends are shown in Figure 1.

If focusing on the proportion of our population that is not only disabled but also living in poverty, we find that between the years of 2010 - 2014, a striking 21.76% of Philadelphians fall into this category. The national percentage on the other hand is 17.64%. Since then, these values have steadily increased for both Philadelphia and our country as a whole; between 2015 - 2019 the percentages are reported to be 24% and

19.38%, respectively (Figure 1). The zip codes with the highest percentages of those living in poverty with a disability in Philadelphia are summarized in Table 1 below.

Table 1. The three highest percentages of the city of Philadelphia's population with a disability living in poverty by zip code. (PolicyMap, 2021)

City of Philadelphia Zip Code	**People with a Disability, Living in Poverty (Percentage of Population)**
19115	37.23%
19133	35.50%
19134	32.80%

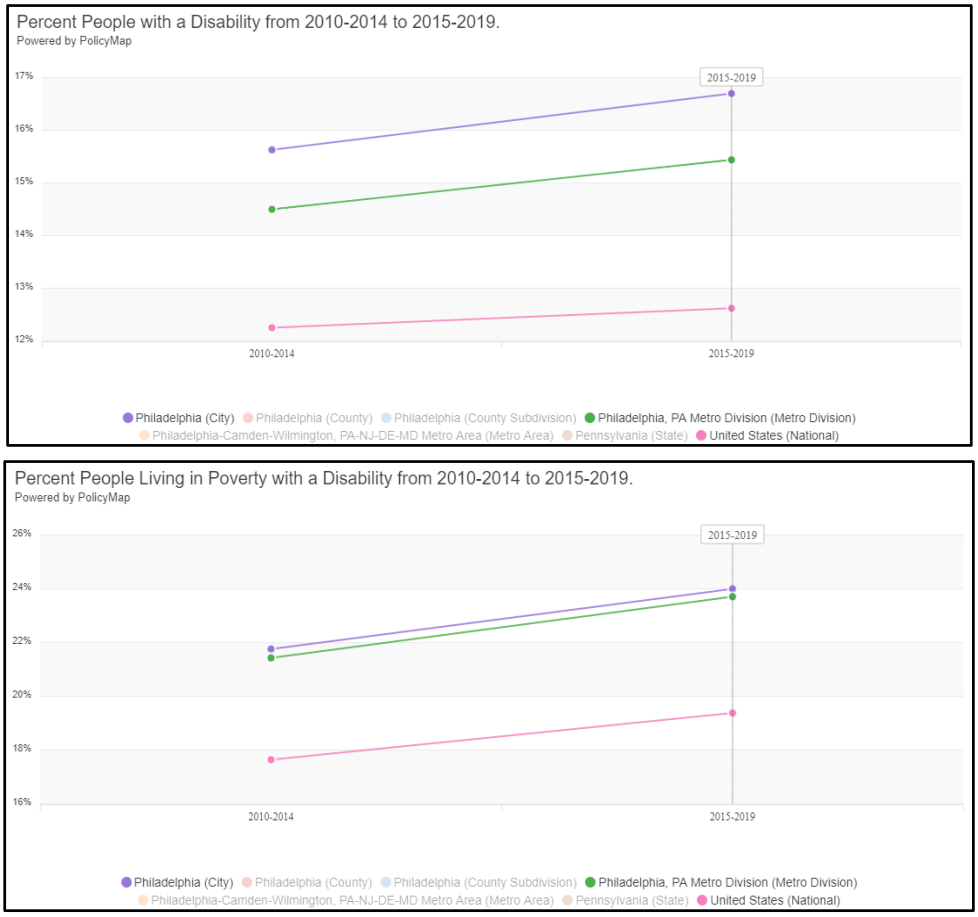

Figure 1. Depictions of the increasing trends in the percentages of people with a disability, and the percentages of people with a disability living in poverty, in the US national and city of Philadelphia from 2010-2014 to 2015-2019 via PolicyMap (2021).

Despite significant strides over the years in improving accessibility for those with physical disabilities in this country, many barriers still exist. Through the 2010 Americans with Disabilities Act (ADA): Standards for Accessible Design, a variety of enhancements have been made to ATMs, parking spaces, and speed bumps for example. However, large-scale alterations such as these are not so quick to implement. Instead, seeking to improve accessibility of those with physical disabilities on a smaller-scale may be an effective means to pursue. Moreover, given the percentage of our population with physical disabilities that also live in poverty, taking costs into consideration for any accessibility improvement endeavour is of the utmost importance. 3D printing,

comparatively accelerated and affordable, has the potential to support this population in countless ways. We now turn our attention to exploring a few different avenues in which 3D printing has been leveraged thus far to improve accessibility for this demographic.

Current 3D Printing Projects: Prosthetics

Much of the academic research hailing from our medical and scientific communities has focused on assisting people with disabilities through 3D printing prosthetics. Traditionally, we consider prosthetics to be in relation to upper and lower limbs (Jelle ten Kate & Breedveld, 2016), but 3D printing has also been applied to dental implants, ophthalmology, and other medical specialities (Schubert et al., 2014).

Jelle ten Kate & Breedveld's review (2016) of 3D printable upper limb prosthetic designs describes not only the force distribution throughout the construct, the kinematic specifications of the each prosthesis and it's joints, durability, and the associated printing costs, but also makes certain to mention the impacts of choosing one printing material over another. At the time of their publication however, anti-bacterial 3D printing materials were not yet available; more recently Zuniga (2018) describes in their report the very real possibilities of 3D printing upper limb prosthetics with antibacterial filament. This advancement improves the overall health of the user by preventing typical day-to-day sources of illness, and is especially vital for those with recently amputated limbs since they are more susceptible to infections (Zuniga, 2018).

3D printing in our medical and scientific communities has gained such traction that even the Radiological Society of North America (RSNA) has started a 3D printing special interest group (Radiological Society of North America, 2021), and the National

Institutes of Health (NIH) has developed a 3D print exchange website, similar to the aforementioned Thingiverse and MyMiniFactory. Aside from scientifically accurate molecular models, a portion of their exchange is devoted to 3D-printable prosthetic devices curated by e-NABLE (National Institutes of Health, 2021).

e-NABLE is an ever-growing, global, online community of volunteers who use their 3D printers to make free or low-cost upper limb prosthetics for people in need (Enabling the Future, 2014). These volunteers create open-source designs for both children and adults, in an effort to help congenital amputees or those who have lost an upper limb due to war, natural disasters, an illness or accident. Since traditional prosthetics are associated with high costs, persons in need of such devices - especially those in poverty or with limited insurance coverage - have few options. The pediatric population in particular, since they require frequent fitting and resizing, are subjected to continual high costs. e-NABLE thus is an affordable and accessible option for these individuals.

While volunteers can choose to work alone, there are also opportunities to join one of e-NABLE's many chapters formed by students, libraries, and other maker spaces throughout the world. In Philadelphia, Drexel University's Dragon Claws is a graduate-student run organization that is a recognized chapter of e-NABLE. However, given the unintended consequences of the COVID-19 pandemic, the group has had to pause prosthetic production and instead concentrate their efforts into printing items applicable to our current plight such as hands-free door adapters, face shield head bands, and face mask "ear savers" (Drexel Dragon Claws, 2021).

Joining a local chapter provides volunteers the opportunity to work directly with

communities in need, and accordingly, allows for the deliverance of individualized devices. This is especially valuable since pursuing a “one size fits all” approach to upper limb prosthetics leaves much to be desired, considering that every user has certain constraints and aspirations influencing use of their prosthetic device.

Current 3D Printing Projects: Miscellaneous Support Items

While a great number of 3D printed assistive devices are in the realm of prosthetics similar to e-NABLE’s initiative, the versatility of 3D printing for improving accessibility is unlimited. Much of the innovation has come from the general population: hobbyists, students, and even those with physical disabilities themselves. Once conceptualized via 3D modeling software, designs can be hosted on websites such as Thingiverse or MyMiniFactory. Both websites are popular choices for sharing user-created digital design files; primarily for free. Of course there are variable material costs associated with the actual printing of the designs, but at least by providing the designs for free, the process is made more affordable.

MyMiniFactory has a section of their website dedicated to hosting designs for accessibility. The section is further divided into providing kitchen and dining aid, daily living aid, visual and other forms of communication aid, as well as supporting mobility, hygiene, and recreational pursuits. From grocery bag handles to switch plates embossed with braille, the online community proves how impactful our creativity can be, and how limitless the possibilities to help others are. A few designs for accessibility from MyMiniFactory are shown below in Figure 2.

Figure 2. **(***Left)* Hackess Handy Holder by Eva Sbaraini, (*Middle)* Umbrella Holder attachment for wheelchairs by "Carlos", (*Right)* Plastic Bottle Opener for Hand Support by Luca Parmegiani

Current 3D Printing Projects: The Inglis Innovation Center

Located along Belmont Avenue in Philadelphia, Pennsylvania, the Inglis House is a specialty nursing care facility that has been supporting people with disabilities since 1877. Their mission is to enable those with disabilities to achieve their goals and live as fulfilling a life as possible - with an emphasis on independence and mobility (Inglis, 2021). Presently, they provide residential care for 252 adults with physical disabilities, and assist upwards of 800 individuals living independently in the surrounding community through a variety of resources.

Residents not only receive medical and nursing care, occupational and speech therapies, and take part in social enrichment/therapeutic recreation programs on-site, but they also have the potential to "create a customized set of opportunities to best address their needs" (Inglis, 2021) at the Inglis Innovation Center. Whether it be through lessons in using a computer to send e-mail or video chat with loved ones, or more advanced concepts such as enabling voice recognition or eye-tracking software, this center aims to

leverage technology - both in terms of software and hardware - to help it's patrons best connect with the world around them. Inglis also has a focus on Smart Home Technology, which includes improved control of the lights, television, thermostat, etc. in one's place of residence. By increasing one's access to and use of technology, Inglis seeks to enable individuals with disabilities to become more independent.

At the heart of the Innovation Center is their 3D printing capabilities. Following an interview with the staff that assesses one's skills, needs, and goals, the Inglis team may create specialized 3D-printed devices to support the individual along their personal journeys. The team installs any software and hardware needed and educates the individual about how to use them. However, while there is currently no fee for assessments, training, or the installation of software or hardware, the individual is responsible for purchasing any of the 3D printed components and the necessary software and hardware accessories. Unfortunately, given the percentage of our city's population that is not only disabled but also living in poverty, Inglis may not be a viable solution for certain communities.

3D Printing Projects: Company Initiatives

Corporations such as Ikea Israel have partnered with nonprofits Milbat and Access Israel to develop *ThisAbles*, a line of 3D-printed accessories to adapt Ikea furniture and housewares for those with physical disabilities (Ikea ThisAbles, 2019). They have also created Youtube tutorials showcasing installation methods of their 3D printable modifications. With many of these designs downloadable for home printing, Ikea Israel has clearly emphasized the importance in increasing inclusivity for users of

their items. From adding handles to shower curtains to providing the means to lift a sofa a few inches off the ground, the team highlights how even small adjustments to commercial products can make a significant difference for people with physical disabilities (Ikea ThisAbles, 2019).

ThisAbles welcomes new product ideas from consumers around the world; in fact, their website includes a section where consumers can either report a modifiable need, or submit a solution. Similar to *ThisAbles*'s aim of developing 3D printed modifications for commonly used household items, this work seeks to discover several unmet needs of those with physical disabilities in Philadelphia, Pennsylvania and in response, design open-source 3D printable solutions in an effort to support their engagement in activities of daily living.

Figure 3. *(Left)* Example of a 3D printable prosthetic arm from E-Nable, (*Right)* "Cane by Me" design from Ikea's ThisAbles program

RESEARCH STRATEGIES

As a part of this capstone, I developed a design (Figure 4) that intends to support those with physical disabilities with getting into, and out of, a bathtub. Muscle weakness caused by Multiple Sclerosis, Myasthenia Gravis, and even in the elderly can make this seemingly simple task quite difficult. Furthermore, repurposing household items (i.e., commercial step ladders) for climbing into bathtubs are not only cumbersome but pose numerous risks to the safety of those with physical disabilities.

Photos and measurements of a bathtub's (Figure 4) height, depth, and thickness were taken and used for reference when modeling the assistive device in Autodesk Fusion 360. Bathtubs having other dimensions can certainly be accommodated; the model can be adjusted to reflect measurements of one's choosing in the software, prior to 3D printing.

The design is meant to be fitted along the edge of the bathtub, so that the individual can climb up the three steps from the outside, and then walk down two steps into the bathtub itself. It can be held by the railings when brought into the bathroom prior to use and lifted by the railings when fitting the edge of the tub in its groove. Of course, the main purpose of the left and right sided railings and guard rail are to provide the individual with the necessary support as they climb into and out of the tub. It also serves as a protective mechanism should the individual have a sudden bout of weakness and feel as if they would fall over. All corners of the steps and railings have been rounded to prevent accidental injury that could arise had normal sharp corners been printed. Railing heights, as well as the step heights and widths were all chosen within standard ranges. Presently, this design is intended to be printed with an Afinia H800+ FDM printer in

ABS plastic. Choosing a honeycomb infill pattern as well as an infill density of over 70% ensures a strong print that is best able to support the weight of the individual.

Future iterations of this design could consider removable railings for increased ease of storage; it could also be designed to be foldable.

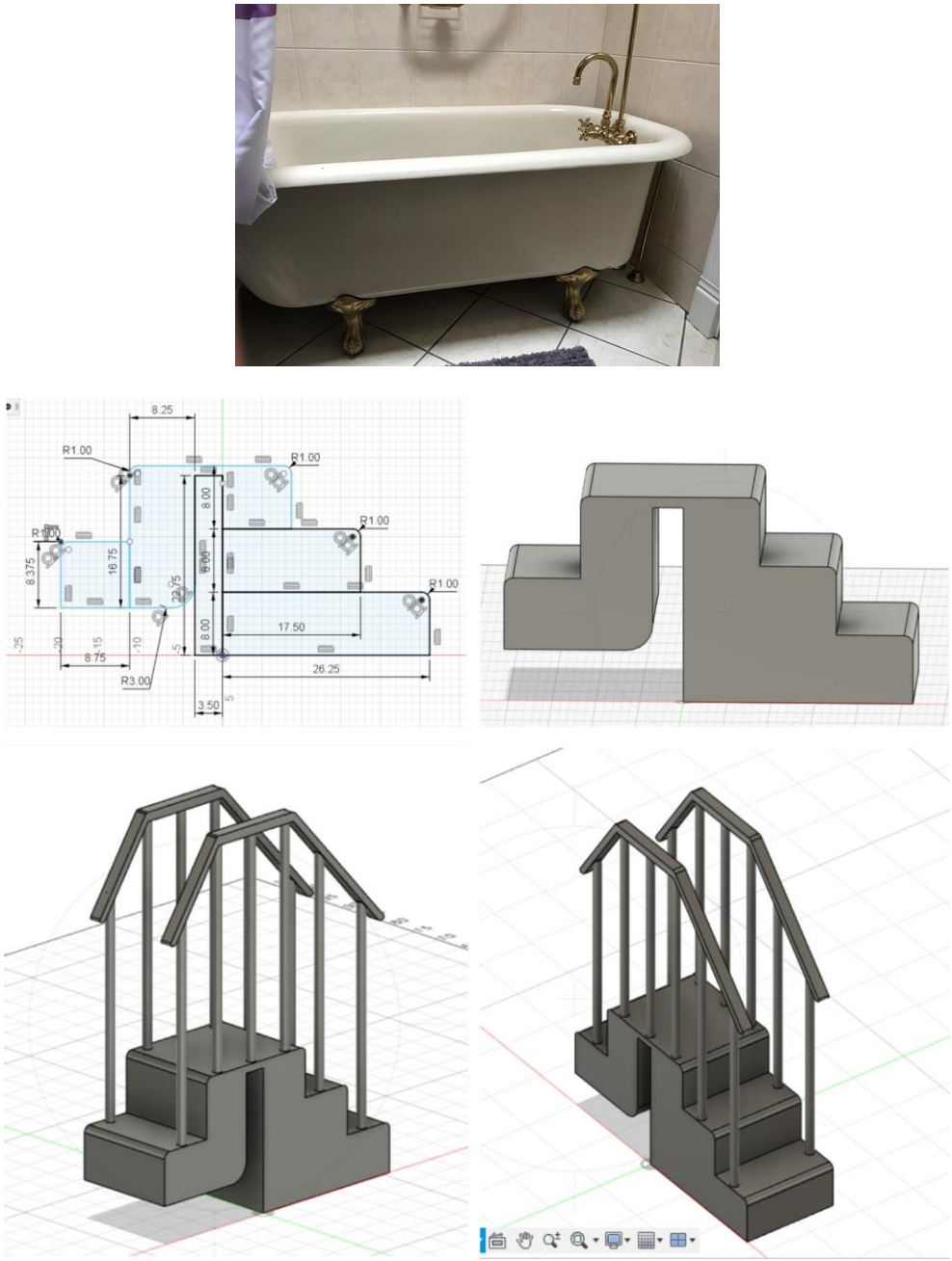

Figure 4. Proposed design by Mashaal Syed. *(Top)* Reference bathtub. (*Top left)* Initial draft with measurements taken from Figure 2, in the 3D modeling software Autodesk Fusion 360. (*Top Right)* Extruded model to span a width of 17 inches, a comfortable area for users to traverse up and down the steps of the printed model. (*Bottom)* Views of the model with both left and right sided railings, as well as a guard rail added for safety and ease of use; the view on the left depicts the portion of the design that would sit in the bathtub, while the view on the right showcases the part that sits outside the tub.

DISCUSSION

3D printing is a cost-effective, completely customizable method of designing assistive devices to support those with physical disabilities. While there are many large-scale 3D printing initiatives to provide support for those with physical disabilities around the world as discussed above, oftentimes there are opportunities to help those in our own communities *ourselves* through these new methods and technologies. We have the flexibility to make our designs as personalized as possible – meaning, our work can target their specific needs and circumstances in ways that commercialized devices may not be able to.

Having the ability to make modifications in 3D models is especially of value, since disabilities arising from various medical conditions have the potential to progress; future alterations to not only this Bathtub Staircase design, but any other 3D printable model, can reflect the changing needs of the individual. The choice of the 3D printing material is also impactful. For example, printing with filament that is antimicrobial, or reinforced with carbon fibers, would increase the longevity of the device.

Those with physical disabilities often have limited financial resources, especially since many of these individuals are unable to work. While there are federal and state grant programs for Pennsylvania homeowners with disabilities, not every individual is eligible for them, nor are there enough grants to support the growing number of persons with disabilities in our communities. 3D printing is comparatively more affordable than seeking to remodel one’s home to account for their physical disability, and has potential to aid those unable to receive grant funding.

Sometimes it's the simple day-to-day activities that we take for granted, that require some innovation to become accessible for those with physical disabilities. By taking the time to listen to them and work *with* them, and by leveraging the capabilities of 3D modeling and 3D printing, we can develop solutions that have more of a multifaceted impact than we without physical disabilities could possibly understand.

RECOMMENDATIONS FOR FUTURE STUDIES

In Philadelphia, The Mayor's Office for People with Disabilities encompasses both the Mayor's Commission on People with Disabilities and the Office of ADA Compliance (*Mayor's Office for People with Disabilities*, 2020). Together, these departments develop and advocate policies to ensure those with disabilities have equitable access to opportunities in the city. It would be advantageous to approach these groups with ideas for policies relating to designing and 3D printing items to help those with physical disabilities. Perhaps the resulting policies would allow for funding of 3D printing initiatives, and provide avenues for those in communities with limited access to receive much-needed resources. Overall, developing such policies would move this sort of initiative from helping individuals, to helping communities at large.

Within our daily activities of living, consider how many potential obstacles there are for people with physical disabilities: how could someone with muscle weakness floss effectively, or make their beds on their own? How could those with limited mobility bend down to lift a laundry basket, and load their washing machine? Not every store has doors that open automatically, so for those in wheelchairs, are they expected to just wait outside for someone to help them?

Especially funding from enacted policies, future 3D printable designs that could address issues such as these could be quickly available for many people in need. Whether it be through 3D printing an adapter to make the small buttons on remotes easier to see and press, or creating a device to help those with limited mobility cut their toenails, 3D printing is a viable method to assist this population in a multitude of ways and should be leveraged.

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