Human-Centered System Design for an Aging Population: An Experimental Study of Footwear Design

by

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Abstract

Population projections[1] indicate that by 2050, people aged 65^+ will account for 25% of the population in Europe and Northern America, and the number of people aged 80^+ will triple to 426 million. With technological and biomedical advances, people now expect to live not only longer, but also better, demanding improved quality of living and working environments to support later adulthood. This new longevity presents opportunities for designers and engineers to engage in participatory, system-oriented design thinking and processes to meet the wants and needs of older users. This master thesis develops an innovative methodology to address the complex systemic social-technological design challenges that this new longevity presents and applies this technology to a novel case study, the design of indoor footwear for older adults.

We propose a Human-Centered System Design (HCSD) approach, combining Human-Centered Design (HCD) and Design Thinking (DT) with select System Engineering (SE) approaches and System Thinking (ST). The methodology was applied to a case study of designing and prototyping indoor footwear for older adults, following a process from inspiration to ideation and then to implementation. Data collected included targeted user and expert interviews coupled with surveys, and market research, as well as from the facilitation of two hybrid participatory workshops. We also used Ultra-Wideband (UWB) assistive technology and computational design tools to prototype future human-centered indoor footwear designs for older adults. We use four lenses to distill and synthesize the results: 1) people; 2) product; 3) platform; and 4) process. The proposed design solution considers not only people's wants and needs, technological feasibility, and commercial viability, but also the adaptability, scalability, and novelty of using HCSD to solve these. Further, we examine the role of the HCSD framework and the participatory design process in contributing to the development of empathy and service tools in pursuit of an age-inclusive society. The study concludes with the proposed solutions including product design, service model, user experience, and technology, as well as a provisional set of design principles for future research on indoor footwear for an aging population.

[1] 2019 Revision of World Population Prospects

Keywords

Human-Centered Design, Human-Centered System Design, System Thinking, System Engineering, Product Design, Design Thinking, Design Process, Aging, Footwear

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It has been a three-year-long adventurous journey to finish my dual master's degrees at MIT. On the road to deliver my master thesis project, there were tears, joy, sweat, and fun with invaluable memories, which is a mixed feeling, especially during the pandemic. I couldn't make such great achievements in life without all the care, support, and love from my dear family; respected mentors; close friends; MIT Integrated Design & Management (IDM) community; thesis supervisors: Professor Maria C. Yang, Professor Olivier L. de Weck, Dr. Joseph F. Coughlin, and Professor Jonathan Chapman; and the supportive MIT labs: MIT AgeLab, MIT Engineering Systems Laboratory (ESL), MIT Ideation Lab, and Industrial Designers Society of America (IDSA).

First and foremost, I want to thank Guo Shi, my beloved wife, my work and life partner, who is a professional automobile design strategist, as well as my parents and parents in law. Without her and our families' full support and sacrifice of their time, I would not have been able to obtain my dual master's degrees at MIT successfully in three years. She always ensures my work and life balance, plans our spring breaks for relaxation and recharging, and takes care of my mental and physical health, even though she herself is busy with writing her own master's thesis at Massachusetts College of Art and Design. I am very lucky to have her in my life. She is the person who has made me realize that life is more than just doing great work. We both have overcome many life challenges, and also enjoyed the bright side of the journey at Cambridge.

My gratitude also goes to Maria C. Yang, Ph.D., Associate Dean of Engineering and Professor of MIT Department of Mechanical Engineering, and my thesis supervisor, for her trust in my work and her open-minded personality to enable me to test my limits in the world of design and engineering. Especially, I have enjoyed the weekly MIT Ideation Lab meeting to discuss and explore every possible design solution and participate in the conversation with guest speakers. She treated every lab member as her family and very kindly supported our initiatives. Her caring for students and enthusiasm for education make her a person I respect. I hope to learn more from her and ultimately become someone like her with a big heart.

I also want to express my thanks to Olivier L. de Weck, Ph.D., Professor of MIT Department of Aeronautics and Astronautics, and my thesis supervisor, for giving my research direction, co-crafting the content integrated with qualitative analysis methods and systemic thinking approach, and encouraging me to push the boundary of design beyond a traditional definition. I still remember taking his course: 16.887 Technology Roadmapping and Development in my first semester at MIT. His passion for teaching, mentoring students, and sharing with us his academic and industry experience has made a positive influence on me by showing me how to become a successful and enlightened leader in the academic and industry field.

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Thanks to Julie Miller, Ph.D., Principal Research Scientist of MIT AgeLab, Taylor Patskanick, Technical Associate II of MIT AgeLab, and Alexa Balmuth, Technical Associate II of MIT AgeLab, for their efforts in mentoring me in conducting the target user interviews with the MIT AgeLab 85^+ Lifestyle Leaders Panel. Besides co-working on the target user interview discussion guide and co-drafting the target user survey, we debriefed and synthesized all interview and data results together for a better understanding of redesigning indoor footwear through the lens of an aging population.

My appreciation goes to Ziyuan (Zoey) Zhu, a graduate student in the MIT Department of Architecture, a talented designer and urban planner, and my great teammate, for trusting me and my work. We've worked on and experienced many different stages of this thesis project: initiating design challenges, conducting expert interviews, ideating creative concepts, prototyping potential solutions, publishing conference papers (dmi, HCII, IDC), conducting workshops (2021 MIT IAP and MIT summer course), and applying for school funding (MIT Sandbox, The Council for the Arts at MIT) and international design competitions. Her positively creative energy, easy-going personality, and passion for experimental design inspire me to design effectively and make me constantly reflect on how to become a better human-centered designer with greater empathy. I cherish our endless debates and continuous discussions of our lives and design to reach an agreement and shared vision. I simply could not have finished my thesis project without her support and company. And the best thing of all is that we co-founded a co-creation initiative—MAKE TO: GATHER to make such an impactful and meaningful influence on our MIT community and beyond!

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Thanks to Pozyx, a Belgian technology company famous for accurate positioning by ultra-wideband (UWB) technology, for supporting and partially sponsoring my thesis project. Aziza Paenen, Customer Success Manager of Pozyx, and Julie Neckebroek, Customer Success Engineer and Project Manager of Pozyx, greatly helped me to install the tracking devices at my MIT graduate student dorm and patiently taught me how to capture and analyze people's indoor trajectory data.

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Author Biography

Sheng-Hung Lee is a maker, MIT AgeLab researcher, MIT xPRO course experience strategist, MIT Office of Sustainability fellow, MIT Governance Lab (MIT GOV/LAB) curriculum designer, and Chair at IDSA Boston. He is inspired by multiple domains of knowledge and perspectives, and he thrives on creating new value for clients on multi-disciplinary teams while working at IDEO and Continuum. He is trained as an industrial designer and electrical engineer, and his approach to problem solving is influenced by his passion for how design and technology impact and can be integrated into society. He has been invited to be a jury member for multiple international design competitions including International Design Excellence Awards (IDEA), Spark Design Award, IDA Award, Golden Pin Design Award, and A' Design Award and Competition. In 2021 and 2022, Lee was invited to be a member of the Industrial Designers Society of America (IDSA) Award Committee collaborating with the leadership team of IDSA.

While pursuing his dual master's degrees at MIT Integrated Design & Management (IDM) and MIT Department of Mechanical Engineering, he co-lectured for the MIT graduate course (11.547/SCM 287 Global Aging & The Built Environment). He was invited as a guest reviewer for the MIT graduate course (15.783/2.739 Product Design and Development). Lee was also invited as a team lab instructor for the MIT undergraduate course (2.00 Introduction to Design). In addition, Lee co-taught and co-led the MIT design course (MAKE TO: GATHER—Interaction Design Webinar + Workshop) during MIT IAP, Independent Activities Period.

Lee graduated with a double Bachelor's degree (Hon.) in Industrial Design and Electrical Engineering from National Cheng Kung University (NCKU), Taiwan. His work has won prestigious awards including IDEA (Gold), iF Award (Gold), Braun Prize, Core77 Design Award, Red Dot (Best of the Best), Spark Design Award, and European Product Design Award (Gold). His works have also been showcased in Dubai Design Week, Venice Design Week, Cooper Hewitt Museum, and MIT Wiesner Student Art Gallery.

In 2019, Lee won a designer in residence scholarship sponsored by the German government, EMMA Creative Center, and Pforzheim University to stay and exhibit his design in Stuttgart. He is a member of World Design Organization (WDO), Asia Designer Communication Platform (APD), Taiwan Society of Technology and Sociology, Phi Tau Phi Scholastic Honor Society, and China Technical Consultants Inc. He taught product design at Fudan University Shanghai Institute of Visual Art and Detao Masters Academy as an adjunct Associate Professor from 2015 to 2019.

Master Thesis Project Honors and Relevant Publications

The following table listed the relevant published 3 journal papers, 13 conference papers, 3 conference poster presentations, 3 hybrid participatory workshops, 3 awarded international design competitions, 2 invited design and art exhibition, 1 blog post, 1 invited public speeches, and 3 fundings that originated from and were inspired by this three-year master thesis project. The research topics cover older adult footwear product, service, and experience design, design methodologies innovation, creative research approaches, hybrid participatory workshop studies, and workshop toolkit designs. This master thesis work was sponsored by MIT AgeLab, MIT Sandbox Innovation Funding, and The Council for the Arts at MIT (CAMIT) Funding.

Master thesis project list of the publications, workshops, awards, exhibitions, and speeches

Research Category	Publication and Authors
2022	
2022 Exhibition and Funding Product Design	**DESIGN: INCLUSIVE—Inclusive Footwear for an Aging Population** Sheng-Hung Lee and Ziyuan Zhu In: *The Council for the Arts at MIT (CAMIT) Funding*
2022 Conference User Interview	**Footwear Design Consideration for an Aging Population from User Experience, Service, and Technology Aspects** Sheng-Hung Lee, Chaiwoo Lee, Maria C. Yang, and Joseph F. Coughlin In: *The 66th Human Factors and Ergonomics Society 2022*
2022 Conference Methodology Studies	**Evolving Ethics in Design Research: Reshaping Design Considerations for Product Designer** Sheng-Hung Lee, Olivier L. de Weck, and Joseph F. Coughlin In: *Design Management Institute (DMI)—2022 Academic Design Management Conference: Design Management as a Strategic Asset*
2022 Conference Methodology Studies	**Human-Centered System Design for Global Supply Chain** Sheng-Hung Lee, Olivier L. de Weck, and Joseph F. Coughlin In: *Design Management Institute (DMI)—2022 Academic Design Management Conference: Design Management as a Strategic Asset*
2022 Conference Methodology Studies	**The Transformation of Design Platform Under System Thinking** Sheng-Hung Lee, Maria C. Yang, Olivier L. de Weck, and Joseph F. Coughlin In: *Digital Research in the Humanities and Arts (DRHA) 2022—Digital Sustainability: From Resilience to Transformation*
2022 Conference Co-creation	**Re-envision a Hybrid Participatory Design Workshop: People, Pedagogy, and Process—A Case Study on Paper Prototype of Smart Footwear** Sheng-Hung Lee, Ziyuan Zhu, Chaiwoo Lee, Maria C. Yang, and Joseph F. Coughlin In: *Industrial Designers Society of America (IDSA)—International Design Conference (IDC)*
2022 Conference (Poster) Computational Design	**Computational Design Experiment for Older Adult's Footwear** Sheng-Hung Lee, Alejandro Carcel Lopez, Maria C. Yang, and Joseph F. Coughlin In: *Royal College of Art (RCA) Helen Hamlyn Centre for Design—INCLUDE 2022: Unheard Voices Conference*
2022 Conference (Poster) Assistive Technology	**Exploring People's Behavior Through Tracking: Ultra-wideband Wireless Radio Technology and Application** Sheng-Hung Lee, Olivier L. de Weck, and Joseph F. Coughlin In: *Royal College of Art (RCA) Helen Hamlyn Centre for Design—INCLUDE 2022: Unheard Voices Conference*

2022 Conference (Poster) Methodology Studies	**Reshape Safe and Sustainable Makerspaces and Laboratories on Campus: An Experimental Study on Material Flow through Human-centered System Design** Sheng-Hung Lee In: *Commons in Design by Swiss National Science Foundation and FHNW Academy of Art and Design Basel*
2022 Blog post Computational Design	**Computational Design Experiment for Older Adult's Footwear** Sheng-Hung Lee In: *DesignWanted Magazine—2022 Technology Category*
2021	
2021 Invited Speech Co-creation	**Human-Centered System Design From Methodology to Implementation—Footwear for the Aging Population** Sheng-Hung Lee In: *2021 International Experience Design Conference (IxDC)*
2021 Participatory Workshop User Interview	**Envision the Future Footwear for an Aging Population** Sheng-Hung Lee In: *MIT Media Lab Tangible Media group (course: MAS.834 Tangible Interfaces taught by Professor Hiroshi Ishii*
2021 Participatory Workshop Co-creation	**MAKE TO: GATHER—Interaction Design Webinar + Workshop** Sheng-Hung Lee, Ziyuan Zhu, John Liu, Wei-Ching Lin, Nahun Kim, and Jonathan Marcus In: *MIT Winter Course (Independent Activities Period)*
2021 Design Award Co-creation	**MAKE TO: GATHER—Rapid Prototyping for Footwear Design** Sheng-Hung Lee and Ziyuan Zhu In: *Spark Award: Bronze (Category: Product, industrial, and Service)*
2021 Design Award Co-creation	**MAKE TO: GATHER—Rapid Prototyping for Footwear Design** Sheng-Hung Lee and Ziyuan Zhu In: *15th Annual International Design Awards: Gold (Category: Design For Society, Design for Public Awareness)*
2021 Design Award Co-creation	**MAKE TO: GATHER—Rapid prototyping for footwear design** Sheng-Hung Lee and Ziyuan Zhu In: *15th Annual International Design Awards: Silver (Category: Education, Teaching aids)*
2021 Jorumal Co-creation	**Reshaping the Online Learning Experience: MIT Co-creation Workshop** Sheng-Hung Lee and Ziyuan Zhu In: *<DESIGN> 2020 Issue 14*
2021 Conference Expert Interview	**An Expert Interview Study of IoT Wearable Technologies for an Aging Population from Product, Data, and Society Dimensions** Sheng-Hung Lee, Ziyuan Zhu, Chaiwoo Lee, Fabio Duarte, and Joseph F. Coughlin In: *Human-Computer Interaction (HCI) International 2021*
2021 Conference Methodology Studies	**Applying a System Engineering Approach to the Early Stage of Product Design** Sheng-Hung Lee, Olivier L. de Weck, Joseph F. Coughlin In: *The 8th Bandung Creative Movement Conference*
2021 Conference Toolkit Design	**Manufacturing Creative Impact: Co-creation Toolkits and Service Design for Remote Hybrid Collaboration Experience** Sheng-Hung Lee, Ziyuan Zhu, Simone Mora, and Joseph F. Coughlin In: *The 8th Bandung Creative Movement Conference*
2021 Conference Toolkit Design	**The Inspiration Design Toolkit: A Human-Centered Design Tool for a System Engineering Course** Sheng-Hung Lee, Maria C. Yang, Beatriz Carramolino, and John Rudnik In: *The ASME 2021 Virtual International Design Engineering Technical Conferences & Computers and Information in Engineering Conference—18th International Conference on Design Education (DEC)*
2020	

2020 Jorumal Co-creation	**Preliminary Discussion on Design Process of Online Workshop "MAKE TO: GATHER"** Sheng-Hung Lee and Ziyuan Zhu In: *<DESIGN> 2020 Issue 22*
2020 Jorumal Methodology Studies	**Preliminary Discussion on the Change of Design Platform Under System Thinking** Sheng-Hung Lee In: *<DESIGN> 2020 Issue 14*
2020 Conference Methodology Studies	**Experimenting with Design Thinking and System Engineering Methodologies: Using a Commercial Cislunar Space Development Project as an Example** Sheng-Hung Lee, John Liu, John Rudnik, Olivier L. de Weck, Joseph F. Coughlin, and Jonathan Chapman In: *Industrial Designers Society of America (IDSA)—International Design Conference (IDC)*
2020 Conference Methodology Studies	**Apply and Curate the Object-Process Methodology (OPM) and the Human-Centered Design to Solve the Systemic Challenge—Use Campus Tour Experience Design as an Example** Sheng-Hung Lee, Chaiwoo Lee, John Rudnik, Olivier L. de Weck, Joseph F. Coughlin, and Jonathan Chapman In: *Design Management Institute (DMI)—2020 Academic Design Management Conference: Impact the Future by Design*
2020 Conference Methodology Studies	**Apply Funnel Model to Design Thinking Process** Sheng-Hung Lee, Ziyuan Zhu, John Rudnik, Chaiwoo Lee, Joseph F. Coughlin, Olivier L. de Weck, and Jonathan Chapman In: *Design Management Institute (DMI)—2020 Academic Design Management Conference: Impact the Future by Design*
2020 Conference Methodology Studies	**A Systematic Thinking Design Research Approach Combining the ConOps with Design Scenario—Use Commercial Cislunar Space Development Project as an Example** Sheng-Hung Lee, John Rudnik, Chaiwoo Lee, Shabnam Fakhrhosseini, Olivier L. de Weck, Joseph F. Coughlin, and Jonathan Chapman In: *Design Management Institute (DMI)—2020 Academic Design Management Conference: Impact the Future by Design*
2020 Participatory Workshop Co-creation	**MAKE TO: GATHER—Rapid prototyping for footwear design** Sheng-Hung Lee and Ziyuan Zhu In: *-ing Creatives*
2020 Exhibition and Funding Product Design	**iFootprint—Future Footwear Product Design and Service Innovation** Sheng-Hung Lee and Ziyuan Zhu In: *MIT Sandbox Innovation Funding*

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Human-Centered Design	HCD
Human-Centered System Design	HCSD
Design Thinking	DT
System Thinking	ST
System Engineering	SE
System Architecture	SA
System Diagram	SD
Concept Of Operations	ConOps
Object-Process Methodology	OPM
OPM Language	OPL
How might we	HMW
Real-Time Location Systems	RTLS
Ultra-Wideband	UWB
Model-Based System Engineering	MBSE

Chapter 1. Introduction

1.1. Motivation and Background

We live in an aging society and we unavoidably need to face transformational social challenges. Our society needs to re-learn and adjust our social infrastructure including services, healthcare systems, education designs, emerging technologies, and business models in the context of people living longer and better with more sophisticated desires.

According to the 2019 Revision of World Population Prospects, by 2050, people aged 65 or above will account for 25% of the population in Europe and Northern America. The number of people aged 80 or above is estimated to triple from 143 million in 2019 to 426 million in 2050 [1].

We often ask ourselves: How old is old? The answer differs from person to person based on their family background, country, gender, education level, and even their health conditions. But without doubt, the average life expectancy has increased. The latest United Nations Population Division data reveals that people's life expectancy (both sexes combined) in the world has increased from 47 years in 1950 to 73.2 years in 2020 [2].

Many factors have influenced the growth of people's life expectancy. Humans have invented advanced technologies, established a sound medical and education system, set up well-developed government policies, and maintained a stable society. Further, with the advanced healthcare system and emerging technologies, we have far less infant mortality and few children dying at a very young age, and also lower rates of maternal death. Therefore, the perception and definition of the term "older adult" has changed [3].

As the size of the aging population has transformed and sped up the development of our world, now is a critical moment to view our society through a new lens of aging and consider our society from the physiological, psychological, governmental, user-experience, family, and cognitive perspectives. Politicians, scientists, educators, and engineers need to get involved. Designers also need to play more critical roles and take bigger social responsibility to solve these socio-technological, systemic challenges of aging collectively.

Therefore, in this three-year master thesis project, we acted as designers to conduct experimental research and redesign indoor footwear for older adults by applying the Human-Centered System Design (HCSD) methodology [4]. The motivation of this thesis project is to build a user-friendly environment for the aging population in our society to raise people's awareness of aging-related issues, to encourage designers to reflect on the problems with existing design methods, and to come up with a holistic, evidence-driven-yet-creative approach, HCSD, to solve complicated, systemic social challenges [5, 6].

In this study, we used indoor footwear design for older adults as a case study to demonstrate the implications and applications of the proposed HCSD methodology [7]. We believe methodology can serve as a helpful guidepost [8], which is constantly evolving and being refined by users, designers, engineers, and people who participate in the process.

Why do we choose to redesign indoor footwear for older adults in this research? Since the level of mobility for older adults is a critical criterion of their life independence, indoor footwear might be the most direct physical product that is connected with older adults' walking behavior to prevent them from falling at home [9].

Research also shows that the majority of older adults who are able to move and wear shoes regard this behavior as a symbol of continued independence and mobility [10], as one pervasive effect of aging is that their feet will undergo a significant loss of cutaneous touch and pressure sensation [11].

We also explore this work from the perspective of both Eastern and Western cultures, with the understanding that there might be cultural differences between the East and the West, in this case around indoor footwear. In far Eastern culture, wearing indoor footwear (slippers) is a social norm. For some Asian families, it has become a life ritual, as putting slippers on represents the shift from outdoors to indoors and the workspace (public space) to home (private space). Indoor footwear is also worn in Western culture, though less pervasively.

Slipper designs for older adults should be not only aesthetically appealing, but also intuitive to wear to make the user experience "invisible/seamless connected." The design of smart footwear should intuitively inform the steps users take without taking too much attention [12], since we observed that wearing slippers is a very subtle and unobtrusive behavior to improve the quality of life for people both physically and psychologically.

From the research, we also discovered that most older adults wore inappropriate footwear that did not fit their feet comfortably: 90% of them had shoes in poor condition whose soles were smooth, and partly or fully worn. Making their foot "sit" inside the footwear might cause damage to the person [13]. Wearing uncomfortable shoes that fit badly and with unsafe features among older adults is closely associated with their forefoot pathology and foot pain [12, 13]. It is a common problem with a prevalence of 22% to 25% in the adult general population, which will increase with age, according to epidemiologic research results [13, 14]. Interestingly, 67% of the survey participants reported that they wore slippers at home. Wearing indoor footwear at home has become a common occurrence among the aging population [18].

These critical findings, observations and research motivated us to redesign a pair of non-intrusive products (indoor footwear) to address users' needs. At the same time, emerging assistive technology for wearables (e.g., tracking their indoor positions, trajectories, pace, and health conditions) has the potential to benefit seniors in a number of ways: fit older adults' feet comfortably, address their foot pathology problems, provide them with the interventions specific to indoor footwear, education service, and remediation [18], and evolve with people's behavior (e.g., walking pattern [19], foot deformity with age), work, and routine in daily lives. Because of their relative newness, most seniors are not familiar with the potential benefits (and also potential drawbacks) of such technologies, so we combined the user-led approach with a design-led approach to focus on smart, wearable indoor footwear.

This master thesis documents the three-year experimental creative process paired with evidence-driven approaches, which were synthesized and called HCSD, including: 1) Human-Centered Design (HCD) methodologies, 2) System Engineering (SE), System

Architecture (SA), and System Thinking (ST) approaches to help us reframe the systematic and complicated aging-related design challenges [20].

During the research, we emphasized how HCSD can play critical roles to be applied with emergent technologies of optimal indoor footwear for older adults. For example, we experimented with the idea of indoor location-tracking footwear for older adults by using ultra-wideband (UWB) technology and establishing a real-time location system (RTLS) to make them safer and enable them to instantly notify their family or hospitals if they fall at home [6, 7, 8].

Regarding the concept of a tailor-made footwear sole, we can translate people's foot pressure map into a set of CADing coordinate data points by using a field-driven design computation approach to produce an integrated and evidence-based footwear sole form that caters to older adults' feet health condition and shapes [9, 10].

The value and outcome of this master thesis project can be summarized in four points: 1) we provided a series of suggested comprehensive indoor footwear design considerations for product innovation, service design, and user experience, 2) we offered key learning points from indoor footwear prototyping experience and design outcome, 3) we exhibited the takeaways of applying this experimental HCSD methodology to the project [26], and lastly 4) we identified potential design directions for further studies (Figure 1.1.).

Figure 1.1. Envision an indoor footwear concept by tacking and translating people's behavioral data to improve home environment design. (illustrated by Sheng-Hung Lee)

1.2. Research Directions and Questions

The research questions are reframed based on the intention of this master thesis project—we want to build a user-friendly environment for the aging population in our society to raise people's awareness of aging-related issues, to encourage designers to reflect on the problems of the existing design methods, and to come up with a holistic, evidence-driven yet creative approach, HCSD, to solve complicated and systemic social challenges. In this study, we used an indoor footwear design for older adults as a case study to demonstrate the implications and applications of the HCSD methodology.

Therefore, we specifically focused on our research questions in two directions: 1) HCSD methodology and 2) indoor footwear design for older adults, in an effort to achieve four key outcomes through this master thesis project that will create socially impactful value.

Research direction 1—HCSD methodology

1. How do we define HCSD methodology concisely by refining traditional HCD processes (focusing on product design) and integrating SE and SA methodologies?
2. How do we translate ideas/concepts inspired and contributed by participants precisely by using HCSD methodology from inspiration, ideation to implementation to reflect people's desirability, engineering feasibility , and business viability [27]?
3. How do we conduct immersive user interviews with older adults through remote technologies paired with HCSD methodology?

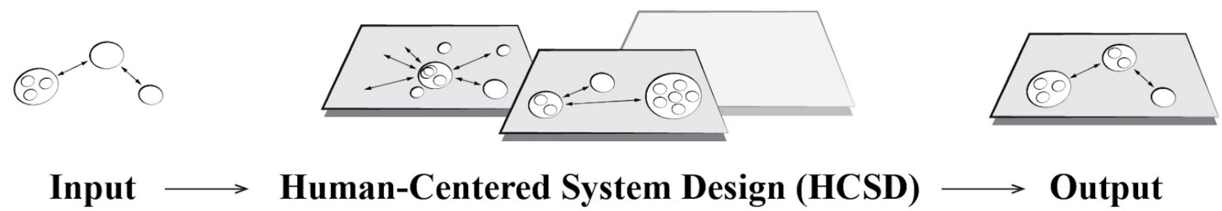
Research direction 2—Indoor footwear design for older adults

1. How do we take comprehensive design evaluation considerations for designers and engineers to design optimal human-centered indoor footwear for older adults?
2. How do we plan, design, and execute business and design strategies for indoor footwear design for older adults?
3. How do older adults receive and use IoT wearable devices? What are their perceptions of IoT wearable devices, e.g., smart IoT indoor footwear?
4. What are the roles, definitions, and relationships of indoor footwear design for older adults in the context of future smart homes [28]?

1.3. Thesis Overview and Research Methods

We structured this master thesis study into three parts: 1) Input 2) Human-Centered System Design (HCSD), and 3) Output, and demonstrated the overall research flow covering both qualitative and quantitative research approach and data. The rest of this thesis is organized as follows (Figure 1.2.).

Figure 1.2. Master thesis project overview (illustrated by Sheng-Hung Lee)



In Chapter 2, we emphasized creative methodologies consisting of Human-Centered Design (HCD), Design Thinking (DT) process, and selected system engineering and system architecture approaches such as Object-Process Methodology (OPM), Concept of Operations (ConOps), and Design Structure Matrix (DSM) to help us understand the pros and cons of each methodology and to learn to curate, apply, and integrate them into the concept of HCSD [11, 12]. We were also curious about studies related to indoor footwear design for older adults. Therefore, we investigated indoor footwear design that covers the product design, older adults' physical and physiological needs, pain points and purchasing behavior, as well as the emergent technologies applied to indoor footwear product design and services. Chapter 2 offers background knowledge for designing indoor footwear for older adults.

Once we had gathered comprehensive in-depth information from Chapters 2, we first applied OPM, ConOps, and DSM to identify research questions we wanted to solve among these complicated and systemic challenges in Chapter 3—Research Methodology: who are the key stakeholders in the system of indoor footwear design for older adults? And how do we build a system architecture to analyze the identified research questions? These system approaches are presented in Chapter 4—System Approach to analyze the research input from the previous two chapters, and give a bird's-eye view to understand the complex social-technological challenges.

Regarding peoples' stories, in Chapter 5—Expert Interview and Chapter 6—User Survey, we shifted the analysis results from the system level to focus on the voices of users including the target audience—older adults, workshop participants, and students with design or engineering backgrounds. In Chapter 6—User Survey, we conducted interviews and surveys for users and experts. We categorized the survey participants into three age ranges: Group A (aged 18~30), Group B (aged 31~60), and Group C (aged 61~100). We recruited and interviewed 31 interviewees from various backgrounds: design leaders, educators, consultants, entrepreneurs, and technologies, to give us their professional opinions about how emergent technologies have shaped older adults' lives and people's interaction with IoT wearable devices and communities [31]. Before conducting each expert interview, we asked interviewees to fill out pre-interview surveys, which gave us a quick overview of their perceptions of technologies, IoT wearable devices, and footwear design for older adults.

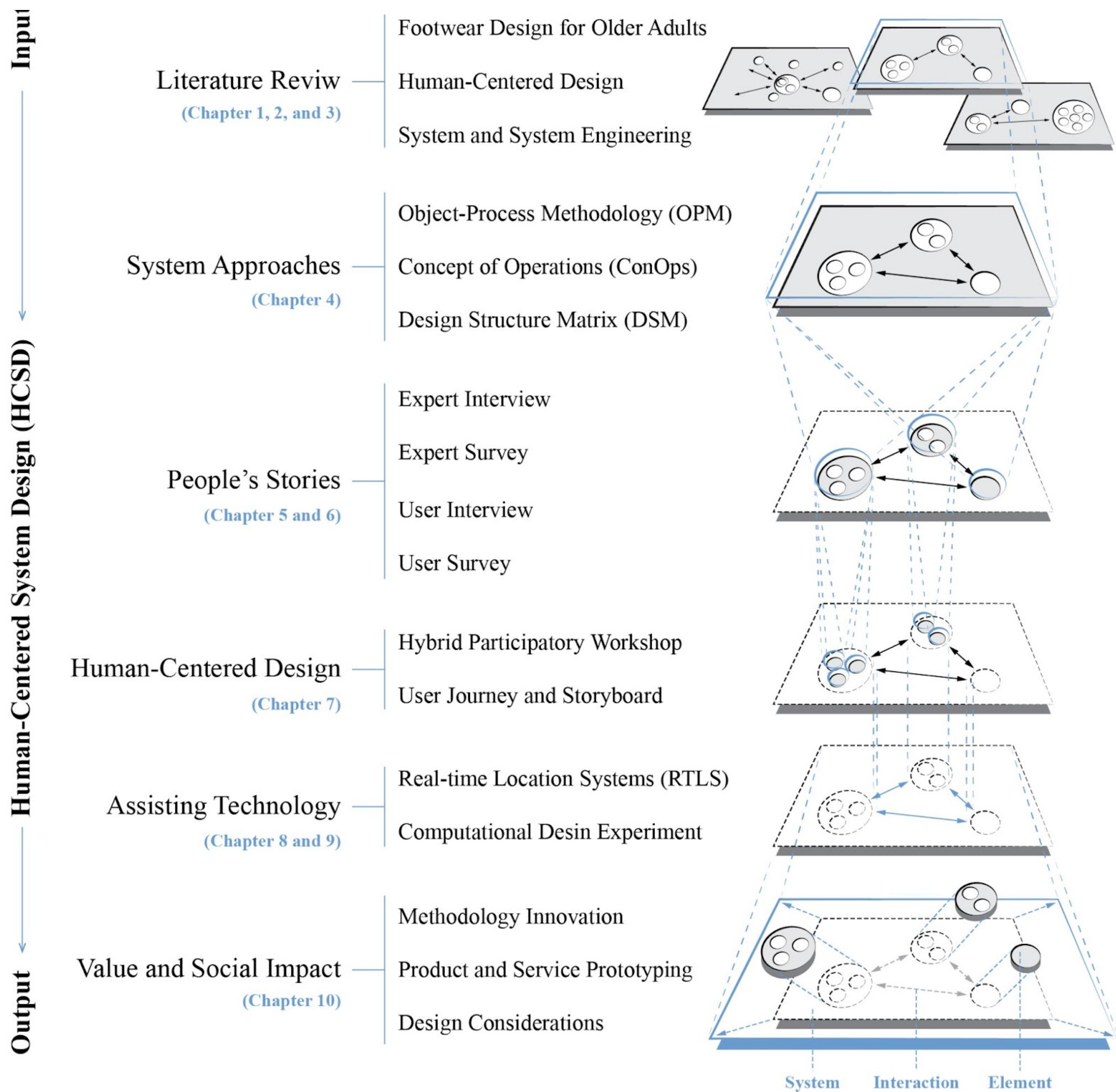
In order to emphasize the importance of applying HCD, we used a typical HCD methodology—storyboard—to illustrate three types of user journeys with multiple scenarios of having a new pair of IoT footwear at home to help us consider the footwear design in the right context [32].

We also documented two hybrid participatory workshops (Chapter 7) to collect participants' feedback and ideas in real time through actually making workshop participants interview older adults and prototype paper footwear models for older adults [7, 19, 20]. The chapter exhibits how we gathered qualitative data, which is critical complementary information paired with quantitative data from expert (Chapter 5) and user surveys (Chapter 6).

In Chapter 8—Assistive Technology, we experimentally applied real-time location systems (RTLS) to footwear design by integrating the indoor location tracking feature based on an emergent technology—UWB (ultra-wideband). In Chapter 9—Computational Design and Prototype, we also tested the field-driven design approach to build a series of computational 3D models of the footwear sole to analyze the relationship between its foam density, shape, and foot pressure data. Both emergent technologies are defined as evidence-driven approaches, which helped us to scientifically analyze people's indoor location data, their walking trajectory information, and foot pressure diagram. We integrated this data into the indoor footwear design process for older adults.

In Chapter 10—Discussion and Conclusion, we summarized the contribution of this three-year master thesis project through the lens of academic, methodological, and footwear design outcomes. We discussed our learnings across the process of experimenting with the master thesis from four perspectives: 1) people, 2) product, 3) platform, and 4) process and also identified the four opportunity areas (Figure 10.2.). From the research, we concluded a set of comprehensive criteria of indoor footwear design considerations for older adults, provided the key learnings from the outcome and process of indoor footwear design prototypes, and suggested further research topics and design directions.

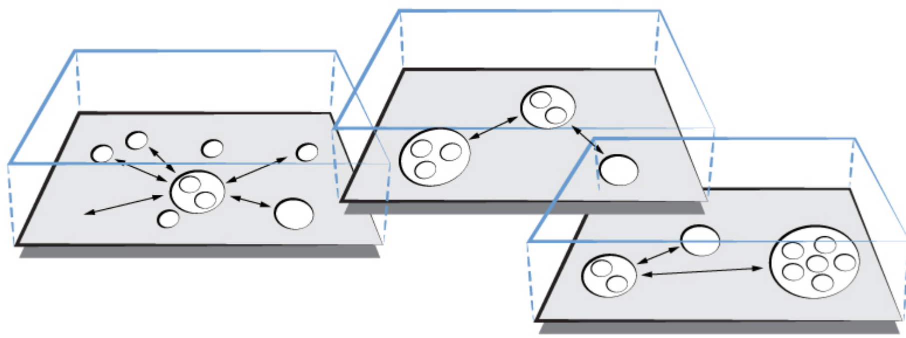
Figure 1.3. Master thesis project research flow (illustrated by Sheng-Hung Lee)



Chapter 2. Literature Review

Essentially, in order to respond to our two research directions from Section 1.2. 1) HCSD methodology and 2) indoor footwear design for older adults, the literature review covers the following three topics: 1) footwear design for the older adult, 2) Human-Centered Design (HCD) methodology, and 3) System and System Engineering (SE). Figure 2.1. demonstrates the visual representation of a process of searching, scoping, and clarifying the above three topics.

Figure 2.1. Clarify the scope and deepen knowledge of the thesis project through comprehensive literature reviews.
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



2.1. Study on Footwear Design for Older Adults

This section discusses footwear design for older adults from six multi-faceted aspects: 1) Recognize people's feet as a sophisticated part of the body; 2) Establish comprehensive criteria for designing ideal indoor footwear for older adults; 3) Decrease older adults' falling risk at home; 4) Consider indoor footwear design from the level of product, to service, to experience; 5) Acquire knowledge of choosing suitable indoor footwear for older adults; and 6) Apply emerging assistive technologies to redesign indoor footwear for older adults.

It helped us to have a holistic view from understanding the complicated body of our feet, potential risk at home relevant to footwear design, expanding the consideration from the level of product innovation to service and experience design, recognizing the importance of education around people's feet health and the suitable criteria of footwear selection, to leveraging emerging assistive technologies, before we zoomed into the specific research questions.

2.1.1. Recognize People's Feet as a Sophisticated Part of the Body

From the literature reviews, we understood that each foot consists of 33 joints, 26 bones, skin, tendons, muscles, blood vessels, ligaments, nerves, and more than 100 soft tissues. All components create an interconnected and flexible structure that allows people's feet to execute various tasks including maintaining balance, supporting the body, and making movement. In the perspective of foot anatomy, our feet represent specific characteristics at different stages of life in terms of age [35]. The evidence above has indicated that human feet are a sophisticated part of our body.

Since people's feet are complicated, so is footwear design. Its design process can be compared with architectural design by considering the ergonomics of the feet, walking postures [36], people's pain points, behavior in life, culture, and emerging technologies. Also from research, there is a burning need to have appropriate footwear for older adults, because the age-related changes will cause changes in foot morphology [35]. Further evidence shows that wearing ill-fitting shoes is common among an aging population and it causes foot health conditions such as toe deformities, corns, and calluses [14].

We need to be much more mindful especially when we redesign footwear for older adults since they are physically and mentally fragile and slow in action compared with the younger generation. For example, the difficulty in putting-on and take-off shoes will become obvious as they become older, while there are no relevant research and design solutions on improving the putting on and taking off footwear mechanisms [37].

2.1.2. Establish Comprehensive Criteria for Designing Indoor Footwear for Older Adults

We explored literature emphasizing the evidence and experimental data of footwear design for older adults that can give us a better and more comprehensive reference to consider physical, psychological, behavioral and social aspects to create future optimal footwear design, service, and experience for older adults.

Essentially, how do we measure the effectiveness and the quality of the design result? Specifically, how do we establish comprehensive criteria for designing indoor footwear for older adults? One study suggested that to design optimal human-centered footwear for older adults, we need to take the following nine points into consideration: 1) a proper anatomical fit, 2) a well-fitting toe box, 3) a limited heel height, 4) a broad enough heel, 5) a firm insole and midsole, 6) an outsole with sufficient tread and width, 7) a beveled heel and a beveled shoe nose, 8) a firm heel counter with a snug fit, and 9) an easy and effective closing mechanism [38].

In the book *Creating Breakthrough Products*, Cagan and Vogel proposed seven product attributes: 1) emotion, 2) aesthetics, 3) identity, 4) ergonomics, 5) impact, 6) core technology, and 7) quality to explain how these attributes (Table 2.1.) allow us to measure product values in relation to a product's usefulness, usability, and desirability [39].

The seven attributes with their values and brief explanations exhibited in Table 2.1. help us systematically consider both functional and emotional aspects of the design process to create better quality indoor footwear for older adults and constructively re-examine the product design and development process for future studies. It is a useful framework to help us establish comprehensive criteria for designing indoor footwear for older adults.

Table 2.1. Seven product attributes, values, and brief explanation
(modified from Cagan and Vogel's value opportunity chart [39] and Justice's interpretation [40])

Attribute	Value	Explanation
Emotion	● adventure ● independence ● security ● sensuality ● confidence ● power	We consider users' feelings that emerge in relation to their interactions with products, services, and experiences. In the study, we emphasized adventure, independence, security, sensuality, confidence, and power.
Aesthetics	● visual ● auditory ● tactile ● olfactory ● taste	We broadly defined aesthetics from multiple sensorial inputs: visual, verbal, tactile, auditory, olfactory, and gustatory experiences in relation to product innovation, service design, or user experience.
Identity	● point in time ● sense of place ● personality	Identity is a context-defined word that contains how we form an expression of products, service, or experiences based on different contexts, personalities, and timing and how it relates to the users.
Ergonomics	● comfort ● safety ● ease of use	We consider not only the human factor of the product design, but also the overall service and experience, including the ease of use, safety, and comfort level of the product or service.
Impact	● social ● environmental	We interpret impact from social aspects and environmental perspectives, including the enterprise's ethical, social, and environmental actions, and how they relate to the consumer, products, services, and experiences.
Core technology	● reliable ● enabling	The technology's feasibility and viability can be interpreted from the reliability and enabling aspects of the technology used for the product, services, and experiences.
Quality	● craftsmanship ● durability	We defined quality in terms of craftsmanship for tangible products and durability for invisible services and experiences, including product manufacturing and flows.

From the study, we understood that among 80% older adults, they suffered foot pathologies as a common health issue and one of the key reasons we saw is because they wear inappropriate indoor footwear [35, 36]: 28% of the study participants said that they had shoes with accurate width and length, whereas 65% had shoes with wrong sizes either too wide or too long or both [33, 34]. Also, the evidence indicated that the majority of older adults fell down and fractured their hip, because they were either wearing inappropriate slippers, were barefoot or wore only socks [35, 36, 39].

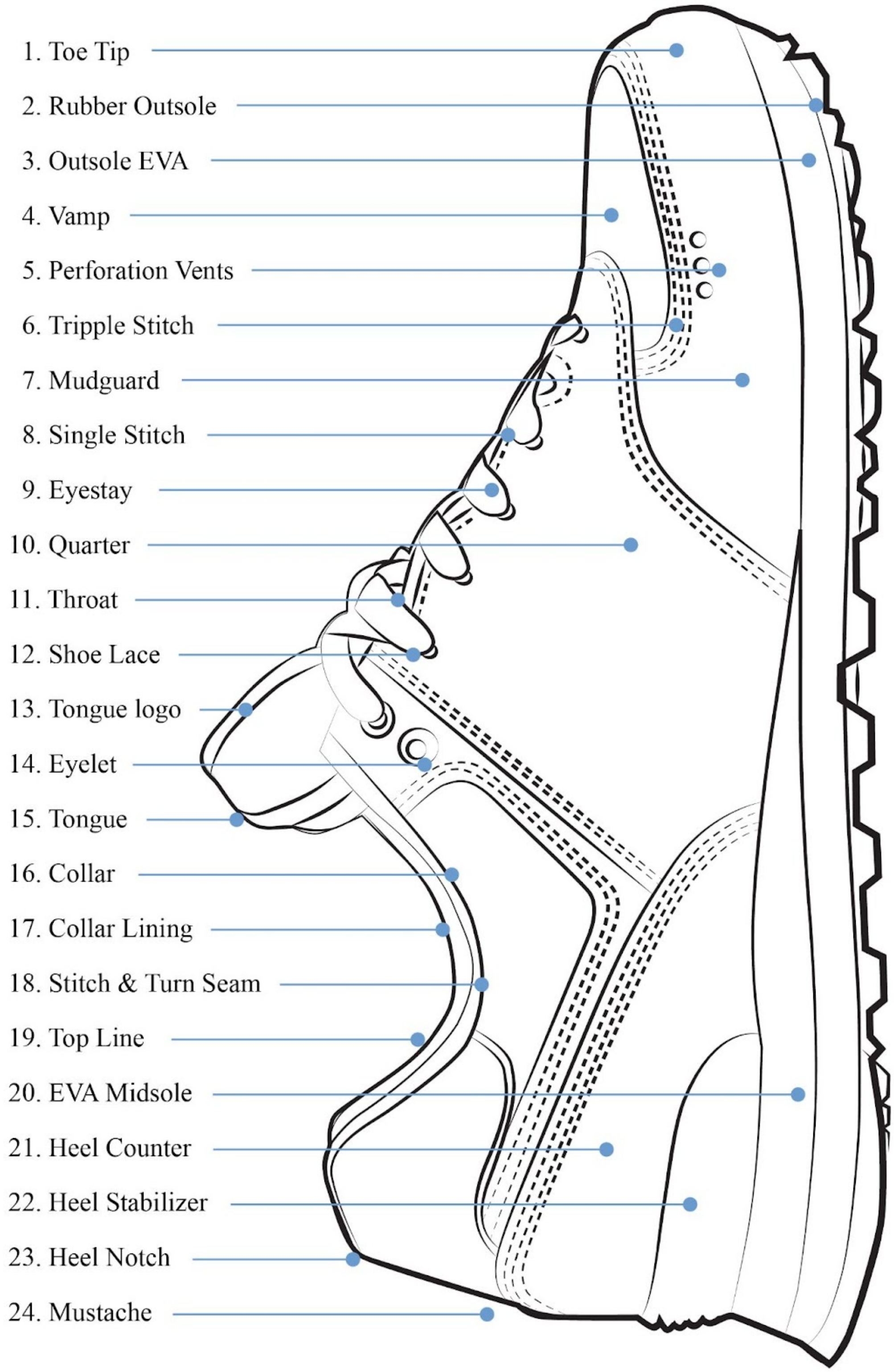
Wong, et al. showed when older adults used orthopedic insoles walking, they showed less static postural sway improving lateral stability significantly. But their balance improvement was adversely influenced if they put on thick socks [38]. Some older adults prefer shoes without fasteners, since they don't need to tie shoelaces by bending down, which provides a great practical observation for us when we brainstorm ideas prior to the footwear design stage [48].

The thickness of the footwear insoles effectively decreased the risk of falling and increase people's postural stability. According to the experiment, the 10-mm-thick footwear insoles revealed the better option for older adults in terms of decreased risk of falling and increased postural stability [49].

In addition, great insole design can simply improve an older adult's foot-sole sensitivity to compensate for the effects of non-neuropathic and age-related decline [11]. Especially when an insole is designed with arch support, a metatarsal pad, and a heel cup, which is normally applied to help relieve foot pain and deformity, it can increase the additional effect of improvement of feet balance [39, 42, 47, 49]. Other than footwear insole design, the further research direction on footwear design for older adults can use systematic investigation to emphasize people's stability when their shoes are designed with high collars and a flared sole [43, 46, 50].

Figure 2.2. Components of a footwear

(the diagram was adapted from the reference material [52, 53, 54])



2.1.3. Decrease Older Adults' Fall Risk at Home

There are many unpredictable and complex factors that make older adults fall at home and people's foot problem normally results from the increased risk of falling which further causes an increased risk of fractures to trigger decreased mobility with a sense of well-being [16].

We view indoor footwear as an interface between the body and the surface, which influences the stability of older adults and thus determines their risk of falling [58]. Thus footwear also has been defined as an environmental risk element for both indoor or outdoor falls [48]. To prevent the older adults from falling, there is a concept of Guardian Slippers, IoT slippers, equipped with the pressure sensors and Bluetooth function to track older adults' health conditions and capture their instant indoor locations [59].

Evi Petersen, Astrid Zech, and Daniel Hamacher suggested that better gait performance is associated with walking with minimalist shoes for both younger and older adults. They also concluded that to reduce the risk of falling, wearing minimalist shoes for older adults can be a safer option compared with barefoot walking [39, 42, 43].

The experiments showed that compared with wearing conventional shoes, wearing minimal shoes might improve older adults' dynamic and postural stability and increase their physical performance while walking [61]. It indicated that footwear design for older adults can be considered to follow the direction of "minimal" to be relatively easily acceptable by older adults from the dimension of comfort, ease of use, and aesthetics [62].

The ergonomic footwear research associated with increased fall risk in older adults demonstrated that for community-dwelling independent older adults, their gait parameter reflected a significantly higher falling risk by wearing an open heel shoe model than high collar shoe model [63].

In summary, we investigated the importance of aging foot assessment and foot pain management, and proper footwear design possibly serves as key factors of fall prevention for older adults [52, 53].

2.1.4. Consider Indoor Footwear Design from the Level of Product, to Service, and to Experience

The concept is not a new idea of designing smart footwear for older adults by integrating monitoring devices and notification systems via smartphones to prevent them from falling at home. Designers need to push the boundary of only designing physical objects, product design, to consider the whole user experience around physical objects, and to prototype people's service experience [30, 31, 62].

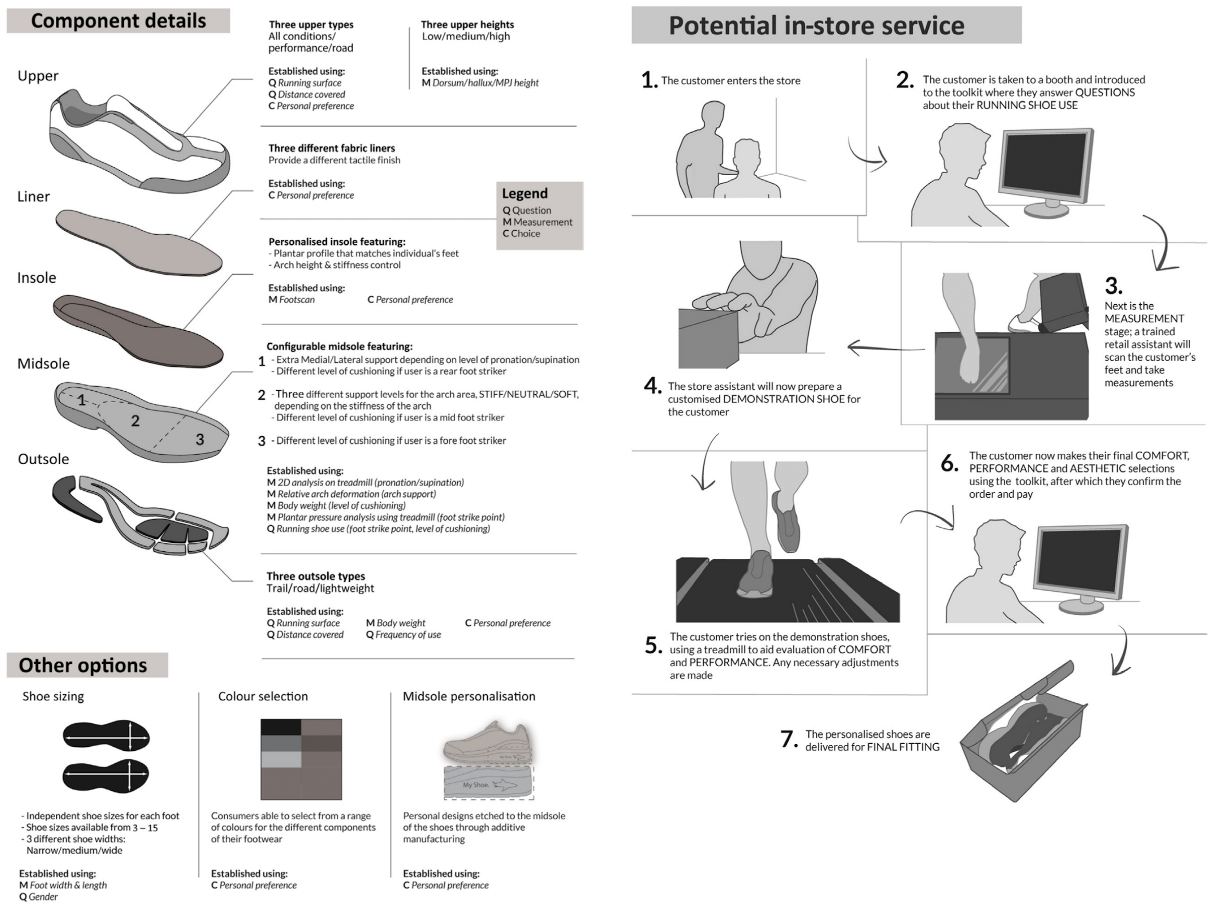
Lynn Shostack coined the term "service design" in 1982 and he thinks a service is like an experience; a service cannot be stored on a shelf, touched, tasted or tried on for size [69]. He also talked about the difference between products and services, which is more than semantic. The tangible products exist in time and space and can be possessed, whereas services are rendered and they exhibit in the format of process or action in time [70].

The definition of service design from Nielsen Norman Group is that it is the activity of planning and organizing a business's resources including people, props, and processes in order to directly improve the employee's experience, and indirectly, the customer's experience [71]. In this study. We not only designed the concept of indoor footwear product design for older adults, but also explored the service components around the product to make the user experience better to address their pain points.

For example, YourStep is an in-store service concept to deliver customized running shoes [72]. It has the following six steps:

- **Step 1:** An in-store expert will take customers to a booth and use the toolkit to answer customers' questions and to understand their wearing behavior.
- **Step 2:** The trained store assistant will work with the expert to take a precise measurement of customers' feet by mobile scanning devices.
- **Step 3:** From the information the expert gathers through the toolkit and scanning data of the feet, the store assistant will prepare personalized demonstration shoes for customers to try and to see if the size of the running shoe, the comfort level, the shoe material, and overall experience fit their overall expectation.
- **Step 4:** The customers will be invited to test the performance and comfort of the running shoes by using an in-store treadmill and give the expert and the store assistant any feedback afterward.
- **Step 5:** Before customers make an order, they will use the toolkit to assist them to select the right comfort level, performance, and aesthetic of the running shoes.
- **Step 6:** The tailor-made shoes are delivered to customers.

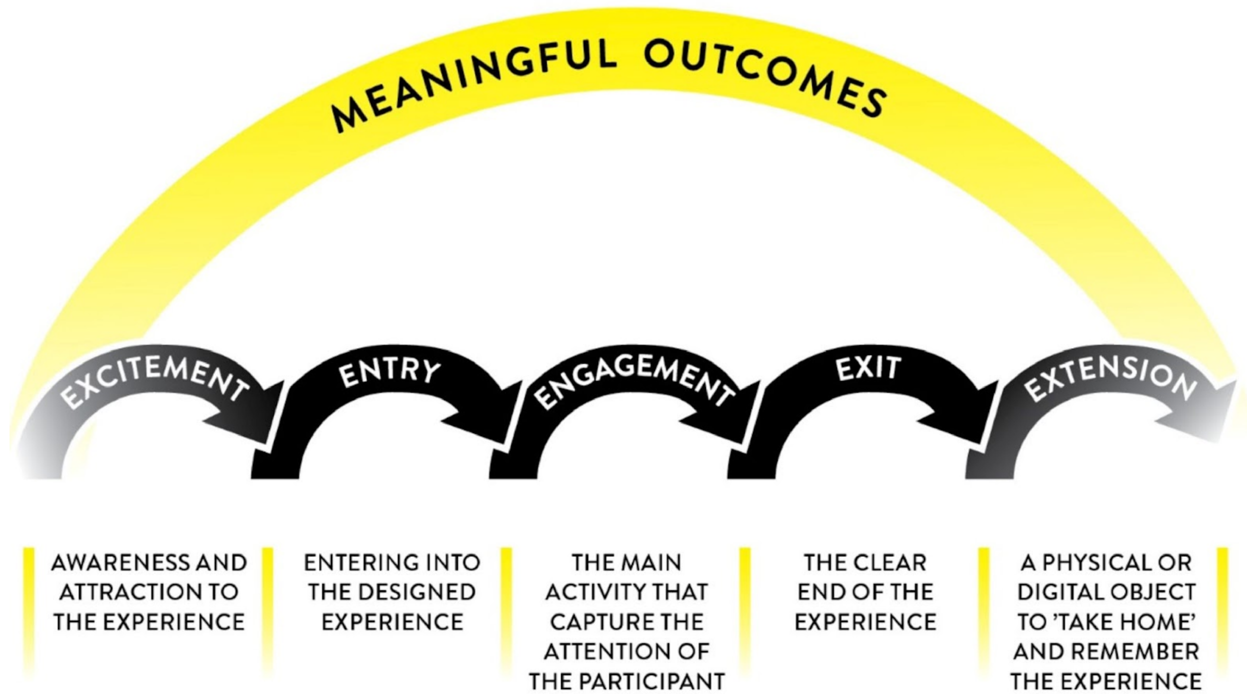
Figure 2.3. The concept of YourStep product and service design: a tailor-made running shoe to meet the needs of each consumer. (source: [72])



The example of YourStep highlights the importance of the user experience and the complexity of the footwear service design (Figure 2.3.). We not only need to consider the benefit and experience of multiple stakeholders e.g., in-store experts, shoe assistants, customers, shoe designers, and even delivery people in the service, but also think of building a sustainable and user-driven indoor footwear design system for older adults.

Among different types of service or experience model, the 5E experience design model modified from Larry Keeley's framework in 1994 can be a great starting point as a reference framework when we plan to design optimal footwear service for older adults [73]. Entice, enter, engage, exit, and extend are the 5E we normally use to identify the key service touchpoints (Figure 2.4.).

Figure 2.4. The 5E experience design model
(the diagram was adapted from Larry Keeley's framework [73])



Besides considering user journey through the lens of service design, we also need to think about older adult's privacy issues in the service model, and their desirability while they wear smart IoT indoor footwear as well as the overall user experience with their family, caregivers, medical team, and other key stakeholders in the systems [59].

2.1.5. Acquire Knowledge of Choosing Suitable Indoor Footwear for Older Adults

From research results, many older adults wear non-suitable footwear for themselves indoors and outdoors and their shoes are not constantly replaced. It is possible that they and their family need to raise awareness and educate themselves on the importance of selecting safe and appropriate footwear or the financial considerations [34, 51]. Studies implied that there is a potential user's need, specifically for older adults, to provide foot care, foot-health-related consultation, and education of choosing appropriate shoes for them [75].

The majority of older adults tend to select their indoor footwear based on comfort instead of safety, and there is insufficient evidence in research and on the market to recommend how to choose safe shoes based on criteria [45]. Older adult's footwear choice reflects not only the footwear fit (e.g., sizing, measurement, width fittings), footwear purchases (e.g., styling and type of shoe) but also their emotions associated with footwear (e.g., comfort of shoes, positive or negative wearing experience, the projection of people's self-esteem) [74]. Meanwhile, they prefer to wear slippers to relieve their toe and hindfoot pain [76].

For example, older adults prefer shoes that are designed with a lightweight structure and covered by soft material e.g., synthetic fabric, leather for the shoe uppers [10], and they can wear and take their shoes off without too much effort. And then they might consider safety issues and the risk of falling while putting them on [22]. However, the awareness of fall prevention should be covered in the education of older adults and their families/caregivers [48].

Older adults' purchasing behavior indicates that they might not have enough knowledge about how to choose the proper footwear according to their feet's health conditions. Most shoe brand companies don't provide professional education through their services to teach people how to select appropriate footwear.

2.1.6. Apply Emerging Assistive Technologies to Redesign Indoor Footwear for Older Adults

Before exploring why and how to apply emerging assistive technologies to footwear design for older adults, we discussed the relationship between emerging technologies and HCD. We think emerging technologies are like a "provocative" medium to enable and increase design opportunities to satisfy users' unmet needs or desires that they haven't thought about [77].

The value of using emerging technologies is to push designers and engineers to not only consider their applications and implications, but also research the core reason why they matter to users. In this study, we defined users including older adults, their families, caregivers, medical team, and other key stakeholders around the indoor footwear design products, services, and experiences.

Footwear design evaluation criteria can be based on three dimensions: quality of life, safety, and mobility of older adults [78]. The state-of-art manufacturing process and technology play critical roles in empowering designers and engineers with more room to create tailor-made footwear designs with modular components and human-centered services that cater to older adults' desirability.

For example, one common technology is additive technology e.g., 3D printing. It has not only greatly reduced the cost of tailor-made shoes for older adults, but also improved the quality of the shoe design, which enables the majority of shoe brands/companies to reconsider the design of shoes from merely focusing on product innovation to service design and user experience around the product [72].

In general, additive technologies such as 3D printed fabrics/products, including shoes, clothes, and accessories, have provided the benefit of customized design solutions. Stratasys [79], a 3D printer manufacturer, has collaborated with designers and artists around the globe to present innovative concepts. Meanwhile, the flip side of applying additive technologies is the cost of time, machine maintenance fees and service, and sustainable business models might be challenging for preparing for high volume needs on the market. Especially, 3D printing for footwear design is still in a nascent stage, because of the product performance and the high cost for customers.

Besides innovation in additive technology, we also explored the computational software/approaches about how we construct indoor footwear 3D models to make them more customizable and cost-efficient. The research revealed the benefit of customized shoe soles in improving the health-related quality of life of community-living older adults. Those who wore custom-made insoles significantly improved their physical and mental health compared to those who didn't [80].

Therefore, in this master thesis project, we partnered with a group of senior engineers from nTopology, a New-York-based software company famous for creating advanced manufacturing and next-generation design tools, by using the field-driven design methodology. It is an approach that allows designers or engineers to make their design variations by changing mathematical formulas, distance, or simulation data—to translate older adults' feet pressure data into three-dimensional coordinates to reconstruct the foam density of a 3D model by computation to redesign the shoe sole [81].

The field-driven design methodology has equipped designers and engineers with unprecedented design freedom and flexibility to control the complex form and structure of footwear. Thus we believe that there is huge potential to transform the footwear design industries from product design, manufacturing, and service strategy, to business models.

Technology can also make older adults feel safer to prevent them from falling down at home. To achieve this goal, tracking their indoor behavior and walking trajectory has become important recently [82].

We also want to explore the use of tracking software and technologies in footwear. For example, before fitness trackers became a trend in 1986, PUMA, the athletic shoe brand, launched the world's first computerized running shoes—RS-Computer Shoe (RS stands for "running system") to integrate tracking technology in footwear which can be viewed as a Fitbit. Meanwhile, Adidas also released its Micropacer shoes that can capture users' running distance, pace, and calories, but it cannot analyze players' performance in terms of speed, path, and position [83].

We are curious to know why the tracking function has not been widely adopted on the market. Many factors influenced the success of market occupancy of smart footwear, including the cost of shoe design and manufacturing, battery life, people being concerned about their data privacy issues, the low resolutions of tracking results, or even that the time is not here yet for customers to understand the application, benefits, and value of smart footwear [84].

Figure 2.5. PUMA RS-Computer Shoe advertisement
(the image source was Lee's article [83])

In this study, we collaborated with Pozyx, a Belgium-based technology company that provides flexible Real-Time Location Systems (RTLS) for indoor tracking, by using UWB (ultra-wideband) technology to identify people's precise dynamic positions with unprecedented cm-level resolution (10-30 cm), which is better than traditional RF technologies [21].

UWB radios have been very popular to solve indoor tracking/positioning problems and shown an enormous potential to be adopted and applied to diverse indoor environments with high accuracy. Most researches on UWB technology still focus on improving the accuracy of the localization system, but the challenge lies in considering the scalability of the system [22]. There are many other emerging indoor positioning techniques such as RFID, WiFi, BLE, VLP, LIDAR, and camera. Our key consideration to use UWB technology in the study is to keep relatively high (e.g., centimeter positioning precision) accuracy with acceptable cost.

In this study, we focus on the following three aspects tied to three How-Might-We (HMW) questions to apply assistive technologies: 1) Additive Technology: How might we use 3D print technology to create tailor-made indoor footwear for older adults? 2) Field-drive Design Methodology: How might we leverage computation technology to design precise footwear models that cater to older adults' foot health conditions? and 3) UWB Indoor Tracking Technology: How might we build a real-time indoor tracking system to prevent older adults from falling and to keep them safe at home?

2.2. Study on Human-Centered Design (HCD)

Typically, from the literature review and the author's working experience, the early phase of the creative or design process is often referred to as the "fuzzy front end" of product development for the whole team because it remained unclear where, how, and why the process would take place [40].

When discussing the word "design," we also need to consider and incorporate the functional, emotional, and aesthetic aspects of an object or environment [85]. It might make the original design process more complicated and hard to grasp.

In Section 2.2., we explain Human-Centered Design (HCD), one of the common creative or design processes, before introducing system approaches and the concept of Human-Centered System Design (HCSD).

We study HCD by starting with understanding its history, context, and key people's stories relevant to HCD. Section 2.2.1. gives solid foundation of HCD knowledge before we move to the next stage of HCD development. In the era of change in our industries, academia, and society, our target users/consumers have become sophisticated and not easy to satisfy and so our design challenges are complicated.

Therefore, in Section 2.2.2. we discuss how HCD has been transformed and evolved to help design leaders, design practitioners, engineers, researchers, and educators not only solve these challenges, but also adjust their mindsets.

Section 2.2.3.summarizes our learning from the current HCD and proposes HCSD, combining the selected methodologies and frameworks from HCD, DT, SE, SA, and ST, and prototyped a partial HCSD approach to indoor footwear design for older adults to refine the methodology.

2.2.1. A Brief History of Human-Centered Design (HCD)

There are many definitions of HCD. Some research also defined it as Design Think (DT), which was coined in the 1990s by David Kelley, Tim Brown, and Roger Martin to distill the creative methodologies into an easy-to-understand term. Professor Don Norman proposed the term "User Experience" in 1993, which was similar to the concept of HCD and DT [86].

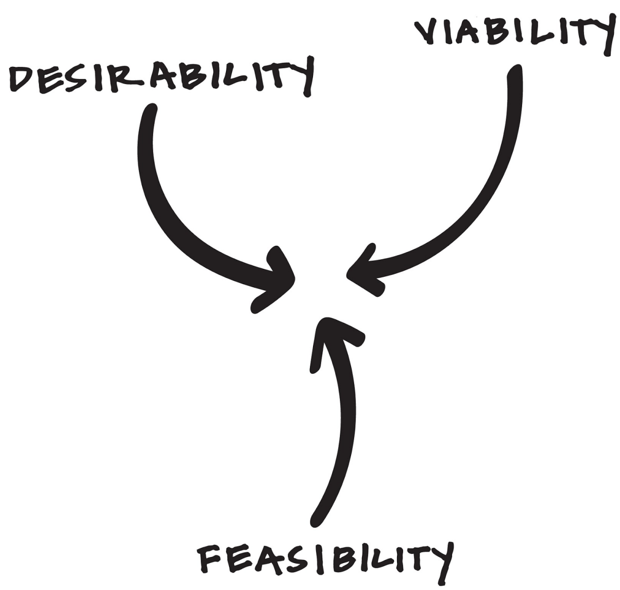
When HCD became popular, some studies started to discuss the difference between user-centered design and human-centered design. The end goal of both approaches was the same: to solve people's pain points and satisfy their unmet needs. The word "user" in the context of "user-centered design" can be defined as an element in a system. We can categorize different types of users based on their gender, age range, occupations, and other segment criteria depending on how we want to conduct user research.

HCD emphasizes users' emotional sides as they interact with products, services, and experiences. Especially when we apply HCD in the design process, we consider the feelings of our users and how we as designers or researchers can be more empathetic in the shoes of our users [87].

However, most researchers, entrepreneurs, and experts from various fields have already applied HCD, a creative methodology, to their own field e.g., business, engineering, and even biology. In the study, to make the HCD term precise and clear, we use the definition of HCD originating from world-leading creative consultancies, IDEO [88] and frog [89], as two main references pairing with other academics, companies, and associations' definitions.

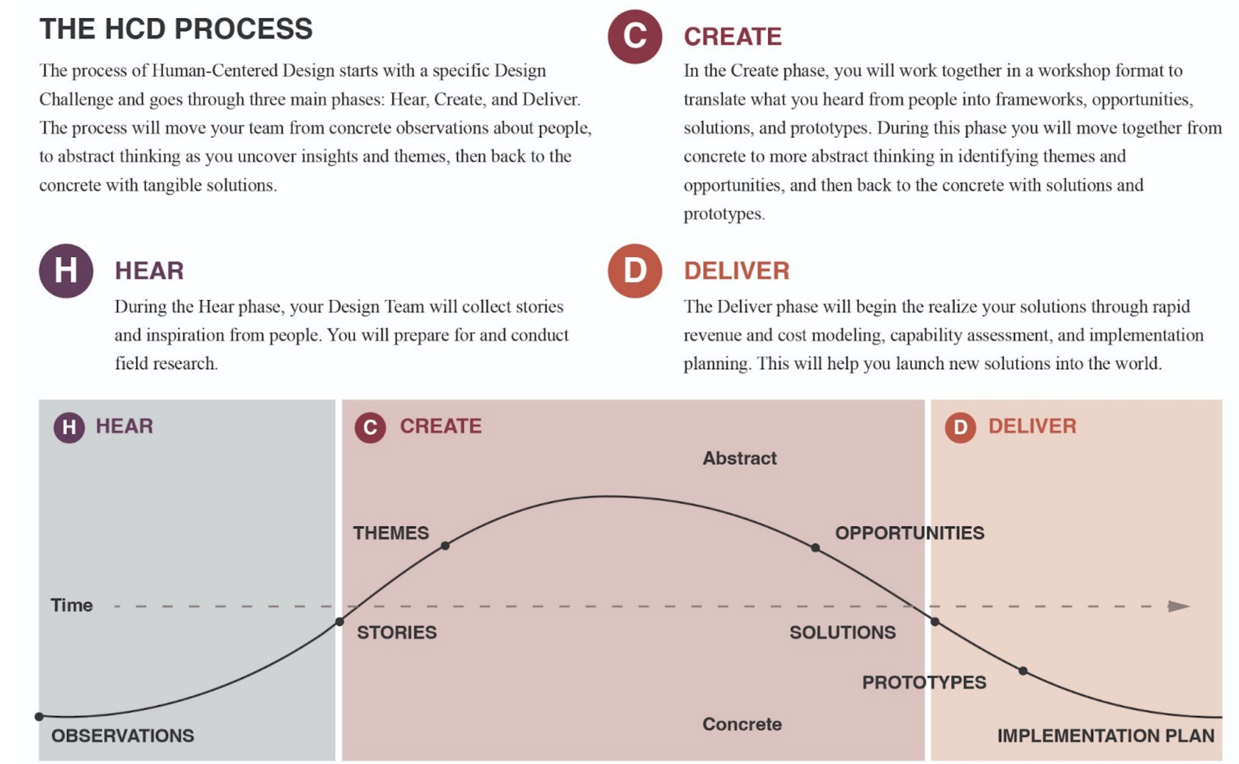
IDEO, an international design and innovation consultancy, has provided a simple version of the HCD definition summarized in a three-circle Venn diagram: 1) the desirability of people, 2) the feasibility of technology, and 3) the viability of business [90]. The overlap of the three circles is where the innovative solutions originated (Figure 2.6.). Most importantly, IDEOers start to define and understand the design challenges from the circle of the desirability of people,starting from people and designing with people, which is the essence of applying HCD.

Figure 2.6. The intersection where design thinking lives
(the source from the diagram of IDEO Design Thinking [90])



The Human Centered Design Toolkit defined HCD as "a creative process and a set of techniques used to create new solutions for the world. The solution should include products, services, environments, organizations, and modes of interaction." [91] In addition to discussing the three key questions from the Venn diagram, they reinterpreted HCD as three main phases: H for hearing, C for creating, and D for delivering, which makes the term HCD not only easy to remember, but also broadens and deepens the meaning of the design process (Figure 2.7.).

Figure 2.7. The HCD process
(the diagram is adapted from the Human Centered Design Toolkit [91])

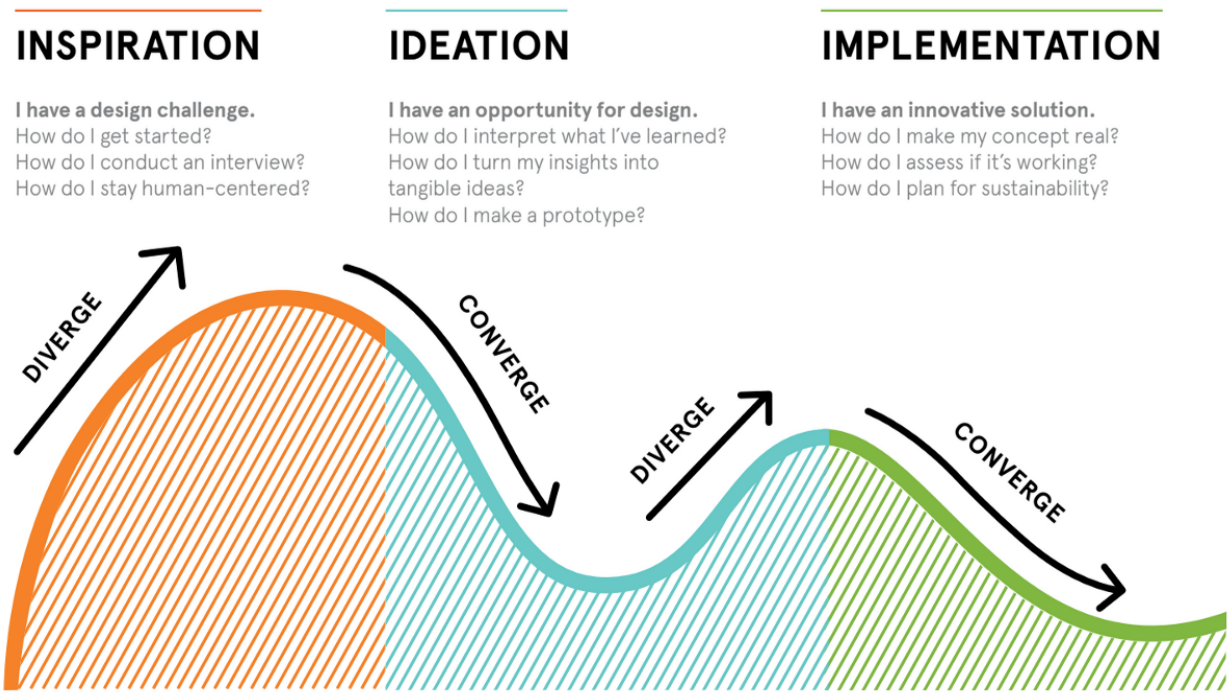


Tim Brown, an Executive Chair of IDEO, said that “Design thinking is a human-centered approach to innovation that draws from the designer’s toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success.” [90] He used many case studies to demonstrate the power of using HCD, DT, in terms of exhibiting techniques and strategies across industries and types of projects from product innovation, service design, and experience design, to organization design [92].

Jane Fulton Suri, partner emeritus and Executive Design Director at IDEO, was one of the few pioneers in the design research field at IDEO to conduct ethnographic research and challenge the previous research approaches and tools, which made designers and design researchers think about more essential questions: What are some of the insights from using HCD to solve problems? How do we cultivate people’s empathy skills and practice them in our lives? How do researchers conduct an immersive research experience with the target users? Suri also proposed design research ethics while using HCD in the fieldwork [93].

The Field Guide to Human-Centered Design from IDEO.org has given us an insightful way to break down the HCD process into three key phases: 1) inspiration, 2) ideation, and 3) implementation. Inspiration is the phase in which researchers or designers are empathetic on what they hear, see, and observant about their target users’ intentions, behavior, and lives to better understand their design challenges (Figure 2.8.). The second phase, ideation, is to synthesize the data and users’ stories from the field to make sense of most information as a preparation stage to generate tons of ideas and then to identify key opportunity areas before prototyping and refining the selected concepts. Lastly, the implementation phase is to launch the final solution to the market and consider how to scale the impact on our society [77, 78].

Figure 2.8. The three key phases of HCD
(the source from the Field Guide to Human-Centered Design [94])



Another legendary global innovation design consultancy, frog, founded in 1969 by Hartmut Esslinger with an industrial design background, has its definition of HCD [78, 79]. Hartmut pointed out one of his guiding principles: "form follows emotion," which demonstrated that emotion originates from people, including users, customers, and designers. This has an impact on the works aesthetically and functionally. It is another perspective to understand HCD.

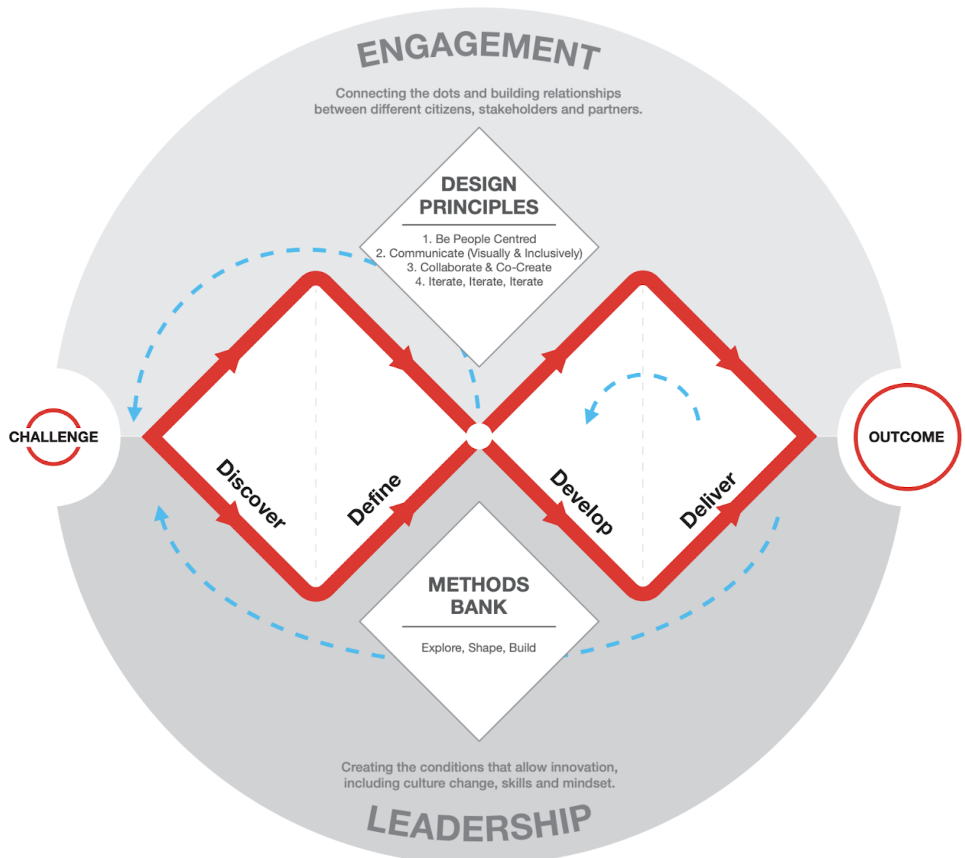
When using HCD, unavoidably, there are tensions between researchers and designers, and users. Since they represent different roles with different responsibilities, they use various creative methodologies within HCD to translate their tensions and resolve problems [98].

2.2.2. Envisioning the Transformation of Human-Centered Design (HCD)

IDEO has been a very successful global innovation design consultancy promoting the concept of HCD and DT in the past four decades. However, in the era of transformation, especially post-pandemic times, most enterprises are facing dramatic challenges, IDEO and other design consultancy companies and professional design associations included.

For example, the UK Design Council has provided the Double Diamond framework since 2004 to interpret a typical design process—an interactive convergent thinking and divergent thinking with four steps: 1) discover 2) define 3) develop 4) deliver [99]. In 2019, they updated this framework by adding system design components (e.g., engagement and leadership) into the framework, which indicated that unlike in the past, designers are now facing more demanding, complicated, and systemic social-technological challenges (Figure 2.9.). Therefore, global professional design associations, e.g., UK Design Council and IDSA (Industrial Designers Society of America [100]), need to quickly adapt their methodologies or frameworks to address this new problem [101].

Figure 2.9. The Double Diamond framework
(the source from the UK Design Council [99])



As an innovative organization, the leadership team needs to quickly adapt to the new situations to respond besides refining frameworks [102]. For example, they have changed their business models, organization structures and culture, and talents they hire, while they rebuild the design consultation services, which has influenced the application and implementation of HCD [103].

In summary, for further research on HCD, we can consider the following three questions: 1) What's the future version of HCD in the context of industry transformation [104]? 2) How do designers apply HCD to solve complicated, systemic challenges for and with people collectively? 3) How do we define the boundary of using HCD to solve these social-technological problems to make a positive impact on our communities?

2.2.3. Apply Human-Centered System Design (HCSD) on Footwear Design for Older Adults

We integrated three selected approaches from SE, SA, and ST to experimentally test the concept of HCSD to address some systemic challenges in an aging population. In this study, we used indoor footwear design for older adults as a case study to demonstrate the benefit of HCSD and improve it for further studies.

Some studies showed the value of combining and comparing SA with the DT approaches and techniques contributing to space mission concept development, which fill a gap in the literature [105]. Other aerospace-related research displayed how to better leverage OPM, ConOps from the SE and SA frameworks and comprehensive analysis to complement the quantitative part of DT methodologies [4].

We applied HCSD across the whole research, since we wanted to use the case study—indoor footwear design for older adults–to prototype three ideas: 1) curate 5E experience design model modified from Larry Keeley's framework in 1994 [73] and OPM [29], 2) integrate design scenario with ConOps [30] , and 3) explore the other potential HCSD methodologies resulting from merging with HCD or DT and SE, SA, and ST. More details and the design of HCSD will be covered in Chapter 3.

2.3. Study on System and System Engineering (SE)

The term "system engineering" was first coined at Bell Labs in the 1940s [106]. We can enhance the clarity of system engineering by understanding the word "system." In the book, *System Architecture,* Professor Edward F. Crawley, Dr. Bruce G. Cameron, and Professor Daniel Selva gave us a definition of a system: a set of entities and their relationships, whose functionality is greater than the sum of the individual entities. A system contains the characteristics of form and function. Form is what the system is. Function is what the system does. The form is the instrument of the function [107].

Eberhardt Rechtin mentioned his views on "system" in the book, *Systems Architecting: Creating & Building Complex Systems*, which says a system is a complex set of dissimilar elements or parts so connected or related as to form an organic whole that is greater in some sense than the sum of the parts [108]. We can simply think of a system as the outcome of things or elements that we collected or gathered to generate something greater.

One comprehensive definition of the term "engineering" from Dr. Avner Engel was to show an all-embracing intention."Engineering is the knowledge required, and the process applied, to conceive, design, make, build, operate, sustain, recycle or retire, something of significant technical content for a specified purpose—a concept, a model, a product, a device, a process, a system, a technology" [109].

Professor Olivier L. de Weck, Professor Daniel Roos, and Professor Christopher L. Magee shared their views on the word system: "a system is a set of interacting components—technical artifacts—with well defined behavior and a well-defined function or purpose, like the individual technical artifact" [110].

They defined the term system engineering, a process for designing systems that begins with requirements, users, and/or modifies an architecture, accomplishes functional and/or physical decomposition, and accounts for the achievement of the requirements by assigning them to entities and maintaining oversight on the design and integration of these entities [110].

In addition to discussing system and system engineering, they also mentioned the new term "engineering system," which is a class of systems characterized by a high degree of technical complexity, social intricacy, and elaborate process, aimed at fulfilling important functions in society.

However, a typical approach to solve problems by using traditional system engineering methodologies is to divide the large complex challenges into several subsystems and solve them, whereas using an engineering system is to integrate the concept of management focusing on planning and control of systems. Introducing the concept of management of systems has broadened the scope of both system and engineering by deepening its definition and amplifying its application and we can apply this to other methodologies in the field of system engineering.

In the era of change, people and organizations are constantly facing complex and systematic challenges that influence us in many aspects of our lives, work, and beyond, including rocket science, transportation systems, complex architecture, manufacturing industries, carbon neutrality, social issues, political problems, and much more. When facing these complicated challenges, we can identify the scope of the system, its form, and its function before applying other SE or SA methodologies.

Applying SE or SA can not only help us to evaluate the challenges whether they are in the state of actual situations or ideal situations, but also help us to achieve the set goals to solve these social-technological challenges in a structural, scientific, systemic approach. In this section, we emphasize three SE methodologies and frameworks: Object-process Methodology (OPM), Concept of Operations (ConOps), and Design Structure Matrix (DSM) to briefly introduce their histories, key definitions, essential applications, and the potential structures and approaches integrating with DT to form HCSD.

2.3.1. Object-Process Methodology (OPM)

OPM is a model-based language and methodology to describe and design a system by integrating three types of entries: objects, processes, and states. According to Professor Dov Dori from Technion-Israel Institute of Technology, inventor of OPM, we can broadly define objects, either in the format of physical or informational, as the things that exist, whereas processes are things that affect objects or might change the states of objects. We normally describe three approaches to express how the process transforms objects, e.g., the process generates new objects; the process consumes objects; the process attracts other objects. Lastly, states can mean the status of objects closely depending on the context in various situations (Table 2.2.).

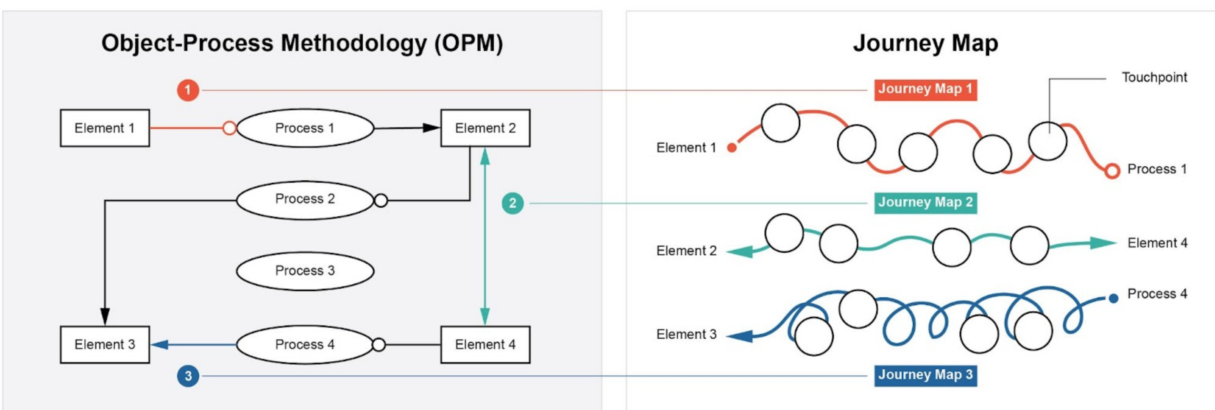
Table 2.2. A brief definition of the key OPM items
(modified the original definition from Dori's book [111])

Item	Objects	Process	State
Brief explanation	Objects, either in physical or informational format, are things that exist in system.	Process, including typical three ways: generating, consuming, and attracting, are things that can transform objects and might affect the state of objects.	States are the status of objects that depend on the context of various situations.

OPM is an intuitive tool that combines simple visuals and graphics with natural language to present the system's functions, structures, and behavior. In OPM, we assume that two aspects, structure and behavior, are inherent in every system. The aspect of system structure is formed through objects and their structural connections, whereas another aspect of system behavior is defined by its process, especially how its process transforms objects, e.g., the process fosters the creation of more new objects, consumes objects, or even changes the states of objects with different conditions in the end.

Since we can use OPM to provide a systemic approach to model different types of systems ranging from almost any field, artificial or natural, we thought its great adaptability can easily and naturally integrate some of the modified DT processes e.g., user journey map to generate a new framework of HCSD (Figure 2.10.).

Figure 2.10. HCSD example: system engineering (OPM) merges with design thinking (journey map) (the diagram originated from the previously published conference paper [4])



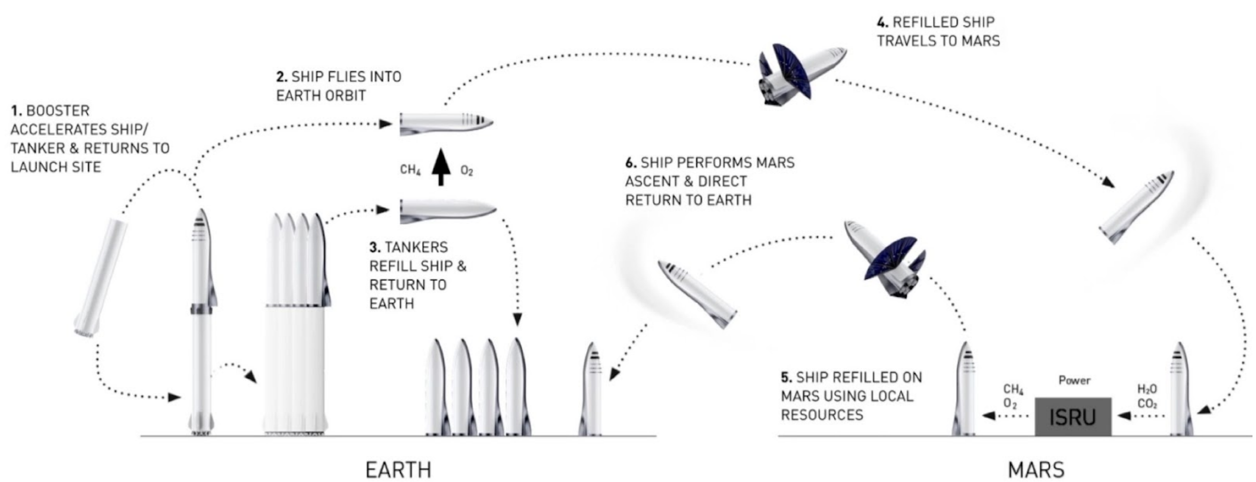
In this study, we don't cover how to apply OPM step by step in detail. Instead, we explain why we thought OPM can be a great system approach to integrate the design process and how we used indoor footwear design for older adults as a case study to prototype our hypothesis of Human-Centered System Design (HCSD).

2.3.2. Concept of Operations (ConOps)

When we describe a system to stakeholders involved in the system, ConOps can be a useful visual and verbal communication tool to describe its characteristics in quantitative and qualitative terms. ConOps has been applied widely in many fields including the space industry, the military, public services, and others.

The aim of using ConOps is to assist the whole project team to have a brief overview of how the system operates and what the system-level requirements are to prepare the future works in the early specification phase. Figure 2.11. is an example by applying ConOp to show the BFR and BFS mission sequence via SpaceX. It is built to ensure participants have a bird's-eye view of the system roadmap, so that the end-users of the system have the clarity to incorporate their decision-making process later while facing critical system emergence.

Figure 2.11. The ConOp of BFR and BFS mission sequence via SpaceX
(the source from SpaceX [112])



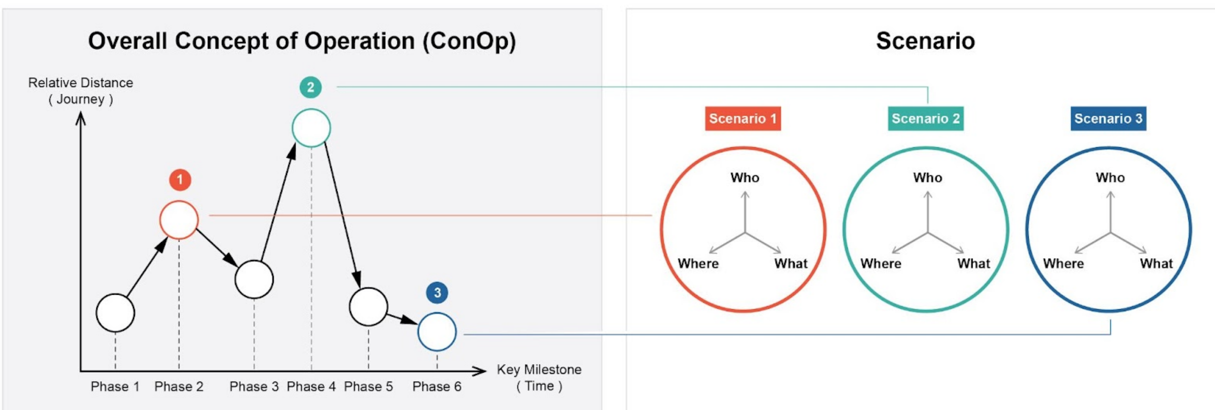
IEEE Standard 1362-1998 suggested the following information that we should use to illustrate informative ConOps for communication: 1) the situation of current systems e.g., background, objectives, and scope, 2) the concept of proposed systems e.g., operational policies, constraints, and support environment, 3) the change of systems e.g., description of justification of change, desired changes, and key considerations, 4) operational scenarios e.g., key stakeholder needs, impact, and context, and 5) the analysis of systems e.g., operational impacts, organizational impacts, improvement, and limitation.

The IEEE Standard 1362-1998 document [113] had inspired us to experimentally integrate the user scenarios into ConOps and explicitly mention the who, where, and what. Scenarios are stories that illustrate a series of activities with actions toward the outcome [114]. Typically a complete scenario consists of an environment with designated states, actors with their personal motivations, tools or objects that actors can use in the settings [114].

Using scenarios from the DT process can help capture the team's attention to discuss the situations in the past and future of usage in systems to focus on what matters most to the team [115]. In this study, we considered the scenario as a conceptual framework to set up experimental conditions not only for design-related practices, but also for science and engineering development to guide the participants to understand the context in an efficient and effective way [116].

Figure 2.12. shows one example that instead of only illustrating the key phase in ConOps, we can experimentally integrate scenarios by at least identifying who are the key stakeholders in this scenario, where are the situations they will face, and what are the tasks they will finish. One study used the ConOps combined with scenarios for the systemic and complex project of commercial cislunar space development and discussed the values of HCSD [4, 28]. However, our intention of using this approach was to enable the participants to easily immerse themselves in the system environment by providing the key system-level requirements.

Figure 2.12. HCSD example: system engineering (ConOp) merges with design thinking (scenario) (the diagram originated from the previously published conference paper [4])



2.3.3. Design Structure Matrix (DSM)

The Design Structure Matrix (DSM), which some researchers called dependency structure matrix or dependency source matrix, is an analytic methodology to study system structures or models for various research areas and applications [117]. We define DSM as a square matrix, which has an equal number of rows and columns, to analyze and present the relationships and connections of each component we put into the system.

We demonstrate one example (Figure 2.13.) to apply DSM to decompose the semiconductor development in 60 steps from setting up targeted customers, to estimating sales volumes, establishing pricing direction, preparing distribution networks, and delivering products to customers.

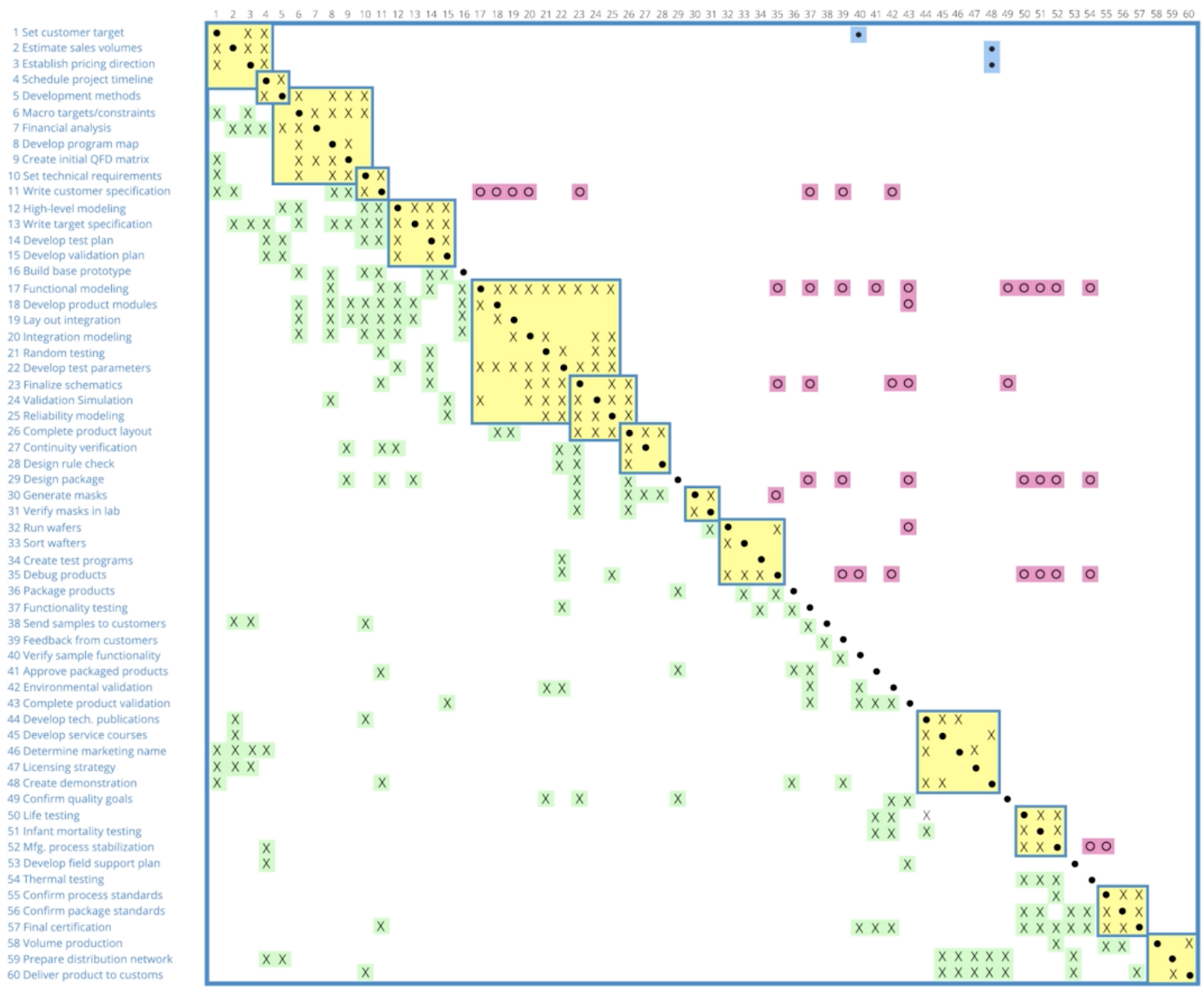
DSM is a useful tool for decoding systems' architecture through a rigorous approach. It is also an excellent methodology for decomposing system processes and organization architectures.

The key benefits of using DSM are its characteristics of intuitive representation, visual nature, and compact format [109].

A DSM provides an intuitive and precise way to demonstrate a complex system by clustering and sequencing the data/components, which reveals the values of this method by determining the behavior and interaction between each data/component. Therefore, DSM has a powerful feature of modularity and can adapt to multiple different research problems: product innovation [118], organization design, and social-technological challenges [119]. In this study, we discussed product innovation DSM.

Figure 2.13. Example of DSM: Semiconductor Development

(the diagram was from Eppinger's book [117])



Regarding instructions of using DSM, we followed the steps and DSM tool provided by MIT xPRO—Architecture & Systems Engineering (Week 4: Modeling with DSMs and Modularization by Professor Steven D. Eppinger, MIT Management Science and Innovation) [120]. In general, Professor Eppinger suggested the process can be broken down into four steps:

1) decompose the system, 2) analyze the system DSM, 3) identify the change propagation, and 4) review the results.

Decomposing the System. We developed a system decomposition based on the criteria that the team agreed on. In this case study, we emphasize indoor footwear features as the main criteria to decompose into subsystems. When prototyping system decomposition, each subsystem should be in the form (objects) of two-level down 7±2 components per level decomposition.

Analyze the System. According to the system decomposition result from Step 1, we label rows and columns on a N x N Design Structure Matrix (DSM) that we developed. Then we experimentally map the form (objects) based on the order of system decomposition.

Identify the Change Propagation. Step 3 is an interactive creative process repeated multiple times attempting to cluster by different orders of the form (objects), the level of components, the expectation of the project, or different criteria to anchor the outcome that the team all align to analyze. Given the result from Step 2, we can make a list of two to five forms (objects) that the team identifies which would make a transformational change propagation impact. The team can discuss internally about the critical subsystems exhibiting the transformational change propagation to effect in the system. In reality, the critical subsystems have only a limited propagation, since there are many contextual factors in DSM.

Review the DSM Results. In Step 4 we identify key subsystems within the clusters and the meaning behind each connection between clusters. This is a critical step to consider the insights that we can generate and how to apply them to our project at a system level.

In the study, we used DSM to analyze product-innovation-related topics—redesigning indoor footwear for an aging population combining with HCSD to explore how to leverage ST approaches paired with the DT process [121].

2.4. Summary and Key Takeaways from Related Works

Here we addressed three domain areas within existing literature: footwear design for older adults, Human-Centered Design (HCD), and system engineering approaches to footwear designed for an aging population. This literature review is the foundation of our understanding of existing research and contributes to an opportunity for proposing a new concept of HCSD in Chapter 3.

2.4.1. Footwear Design for Older Adults

1) Raise the awareness of footwear health across different generations.

According to the literature reviewed, there is a lack of education and public policy dedicated to equipping consumers with the right knowledge and skills to measure and select the right pair of shoes and know when to seek professional medical advice as needed as they age.

Big footwear companies (e.g., NIKE, Adidas) sell footwear products, but do not provide foot-related health services to help, diagnose or track consumers' foot health status quo. This includes their wearing experience(s), comfort level, and parts they need to change or adapt.

Older adults may especially benefit from these services; our feet start to deform and become asymmetric as we age. Our current models of footwear design do not provide us with affordable or accessible tailor-made footwear design. Such shoes are either too costly for older adults to purchase or there is a lack of guidance for both designers and older consumers and their families to follow.

How do we start to initiate collective awareness of footwear health and care for older adults starting with the younger generation? This awareness is about more than just people's footwear health. It is interconnected with the education system, people's family culture, government policies, people's life and work style, and their personal health conditions. Therefore, when we start to think of re-designing indoor footwear products for older adults, we need to consider this re-design as containing a series of systematic challenges.

2) Footwear service design is as critical as product design.

Designing a pair of tailor-made footwear soles and shoes can be done by applying advanced fabrication technologies to save on the costs of customization, such as time, labor, and the design, manufacturing, and product shipment phases. Bigger integral questions should be asked like: how might we identify our target users' unmet needs; how can we address those needs through technology and science; and to what extent can we embed these solutions into the current footwear design and development system, integrating with diagnostic medical services, to deliver a better user wearing experience that improves people's quality of life, especially for older adults and those who care for them.

Essentially, the majority of studies and designs reviewed focused on how to design better indoor footwear products for an aging population, but very few mentioned the importance of service and experience components. When companies, designers, engineers, and researchers are passionate enough to design tailor-made tangible products, we need to pause and examine the accompanying service design and user experience around the products themselves. This is one way to make all great design solutions more sustainable and human-centered.

2.4.2. Human-Centered Design (HCD)

1) HCD is not a noun, but a verb that can be applied to various socially impactful challenges.

From the literature, we found that most HCD material and research originated from design case studies even though many designers and design studios had already used these methodologies in application on various research topics, including the aging-related challenges present in this study. In fact, HCD is an invaluable design approach and has been applied across many disciplines: manufacturing, social science, sustainability issues, and more. HCD is also not a slogan. It is an actionable design process from inspiration, to ideation, to implementation with comprehensive consideration given to find the sweet spot among people's desirability, business feasibility, and technology viability.

2) Scale broader social impact by using HCD.

One of the critical challenges of applying HCD is to scale its social impact by solving large complex systemic social-technological challenges. In addition to conducting user interviews and surveys or facilitating a series of participatory design thinking workshops as a traditional way to follow the HCD process, what might other effective approaches be if we need to manage a large sample or a large amount of data in a short time? How do we apply HCD methodologies to adapt to differing complex situations with reasonable timelines and resources? These common problems are bottlenecks designers or people who use HCD will constantly face.

Imagine if we need to prototype a space satellite by using HCD in a constrained time and with limited resources. Can we do it under the current HCD process? How much time and money do we need to invest if we just follow the traditional HCD process?

Therefore in many industries, some pioneer design-related creative agencies and companies have started to think how to refine HCD and integrate some system thinking/design into the HCD process to solve these large, complicated social-technological challenges. IDEO has already begun creating related job positions (e.g., system designers, organization designers) to deal with the burning needs of organizations or industry transformation projects [122].

2.4.3. System Approaches

1) Demonstrate examples of using HCSD.

In the study, we researched the views and definitions of a system, SE, SA, and ST to get the whole picture of the concept, and we reviewed in detail three system approaches: OPM, ConOps, and DSM, for the purposes of building a meaningful and impactful HCSD model.

A better understanding of system approaches helps leverage their benefits and integrates them into the HCD and DT processes. For example, we experimentally combined OPM with a journey map to give each process link between objects a new meaning and brought a human-centered lens into the systems thinking. Another example was to add scenario design to each node of phase in ConOps to inform explicitly the who, where, and what. This minor change can efficiently help the project team identify the key stakeholders in the scenario, the situations they will be in, and the key challenges they will need to overcome.

2) There is no perfect HCSD.

Further studies must explore other system approaches besides OPM, ConOps, and DSM and their ability to merge with HCD or DT. Case studies can be used to demonstrate and validate the concepts of HCSD. We found that there is no perfect system approach or design process. Realistically, we cannot create a universal HCSD to solve any systemic and complex problem. It closely depends on which types of challenges we are going to solve (e.g., social impact projects versus product innovation projects versus or service-and-experience projects). Then we can identify which parts of HCSD can be used intentionally. In summary, we defined HCSD as a context-driven framework strongly influenced by the types of challenges that designers, engineers, or researchers are going to solve.

Chapter 3. Research Methodology

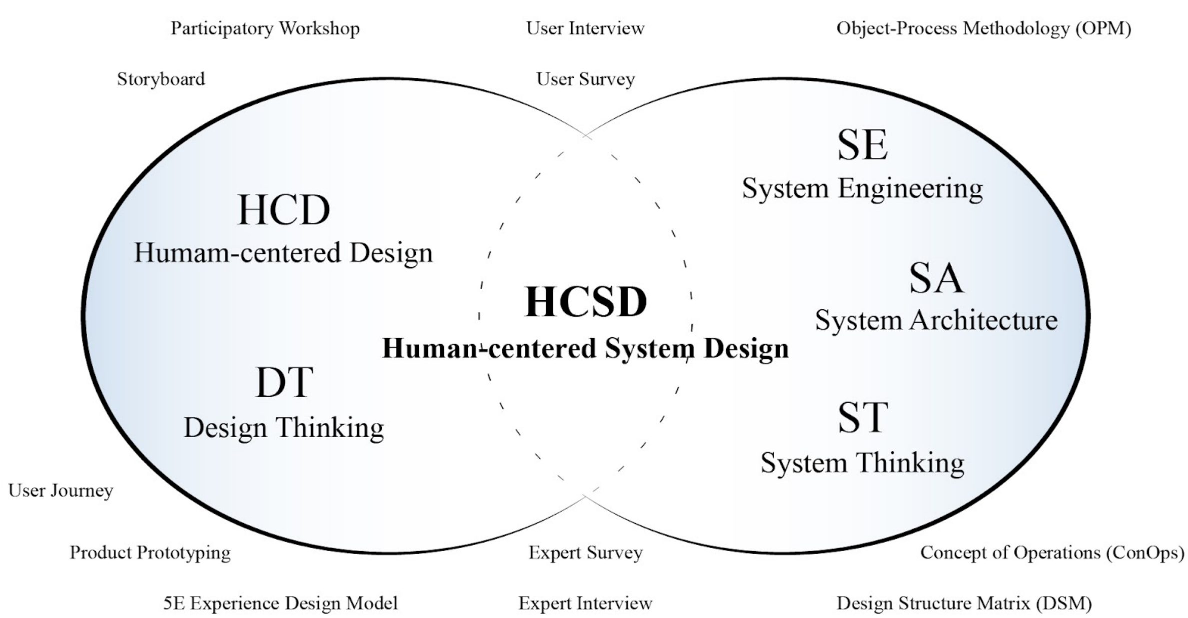
3.1. Research Structure and Human-Centered System Design (HCSD) Framework

An overview of this master thesis project appears in Figure 1.2. It includes a proposed Human-Centered System Design (HCSD), that incorporates an experimental framework curating Human-Centered Design (HCD), Design Thinking (DT) and selected System Engineering (SE), System Architecture (SA), and System Thinking (ST).

The purpose of integrating these selected methodologies from the field of design and system engineering is to help designers and engineers to not only solve large complex systemic social-technological challenges, but also to evaluate, and present the solutions through the lens of HCD. We curate the advantage of using HCD by considering people's desirability, technology feasibility, and business viability by using the selected SE frameworks to scale the design outcomes and amplify the influence in a more systematic and scientific way. Thus, applying HCSD can empower designers and engineers with more flexibility while solving experimental socially impactful projects. We illustrated the relationship between each HCSD component and how it bonds meaningful connections.

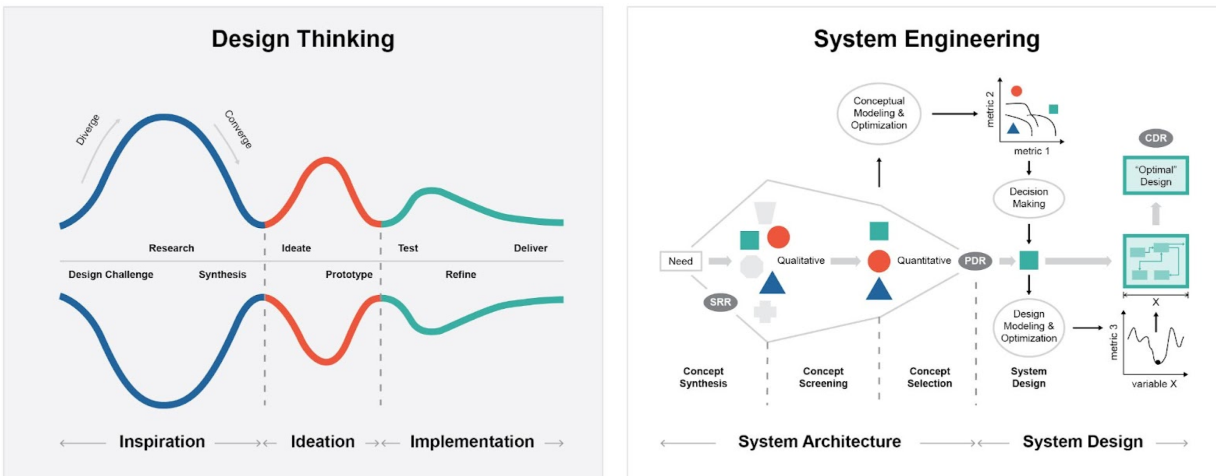
In Figure 3.1., we can see that HCSD is generated across the overlap between two circles, design and engineering, whereas outside the two circles, there are methodologies or frameworks that we used in this master thesis project. HCSD is an early concept curating and integrating two different domains of knowledge and approaches to create new values and methodologies to solve systemic and complicated challenges. We want to use this research to prototype, evaluate, refine some ideas designed for HCSD for further study.

Figure 3.1. Propose Human-Centered System Design (HCSD) framework
(illustrated by Sheng-Hung Lee)



In Chapter 2, we thoroughly studied HCD, DT, SE, SA, and ST to understand the history of methodologies development, frameworks design process, key person of the approaches, limitations, and potentials of each methodology. Thus we encapsulated and organized our knowledge and learnings in Figure 3.2. to compare the difference between DT and SE in a bird's-eye view. The DT diagram (left) was modified from Stephen Gates's diagram and the SE diagram (right) was adapted from the System Engineering diagram from the MIT Department of Aeronautics and Astronautics.

Figure 3.2. Comparison of the design thinking framework and system engineering approaches (the diagram originated from the published conference paper [4])



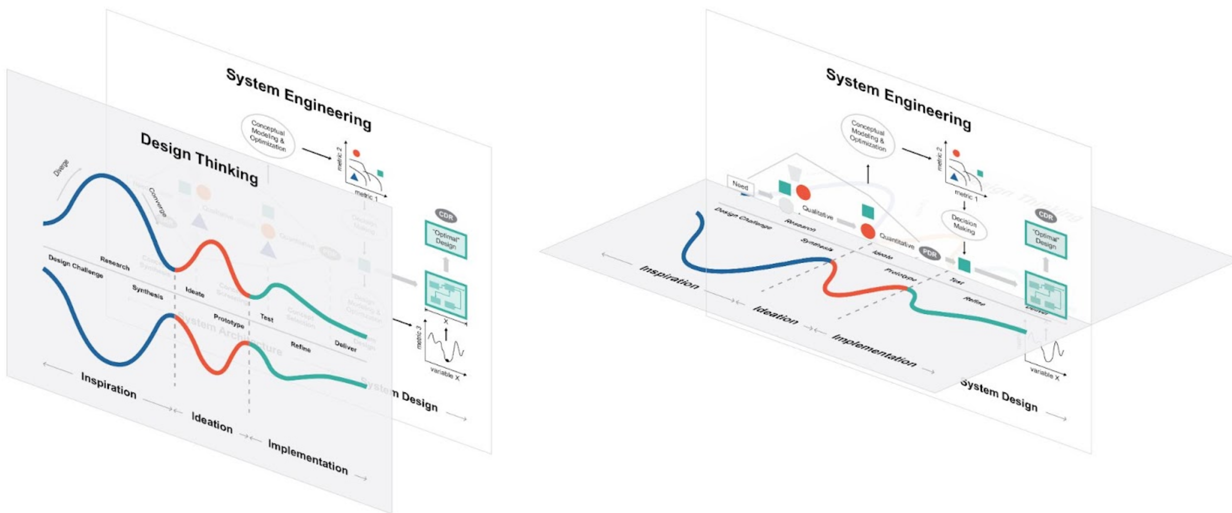
Surprisingly, we found that there were some similarities: 1) contain divergent and convergent processes of each approach; 2) consist of 8 to 10 key steps of each methodology; 3) start from holistic views of the system to narrow down to a specific topic to solve, and shared features in terms of the methodological structure (See Figure 3.2.).

Therefore, we proposed the concept of HCSD was to reimagine how to curate and merge DT and SE to help designers, engineers, researchers, and educators have the right capabilities/skillsets and mindset to solve these large, complex and social-technological challenges from various levels of product, service, experience, to society.

Figure 3.3. was our initial thoughts to visualize this HCSD idea in a simple way. There are still many aspects we need to re-consider, e.g., What are the major methodologies that we should select among all DT and SE? How do we evaluate the effectiveness of using HCSD? What's the matrix for the success of HCSD? What are the instructions in terms of the sequence of applying these approaches to make HCSD not only meaningful for HCSD users, but also impactful to our target customers, key stakeholders, businesses, and society? How do we scale and promote HCSD so that more people can appreciate its value?

Figure 3.3. Visualize how we can prototype to curate and merge design thinking and system engineering approaches.

(the diagram originated from the published conference paper [4])



Regarding research structure to prototype the concept of HCSD and validate some of our hypotheses, in general, we followed the model from Figure 1.2.: Gathered information and data as input. And then we experimentally applied HCSD to an indoor footwear design case study.

In this case study, its experimental creative process included: 1) covering the comprehensive literature reviews; 2) conducting in-depth interviews and surveys with both users and experts; 3) hosting hybrid participatory workshops to brainstorm and co-create ideas; 4) using assistive technology to help prototype user experience and to validate the selected concepts; and 5) experimenting with computational design methodologies pairing with HCSD.

Lastly, we discussed the social impact and value of not only the indoor footwear design, but also the contribution from the experimental creative process and HCSD methodology in Chapter 10.

3.2. Project Partners Overview

This master thesis project is sponsored by and partnered with the four different laboratories from MIT, Carnegie Mellon University (CMU) school of design, four companies, and many experts, scientists, designers, and researchers from various fields to conduct this three-year research and design project collaboratively (Table 3.1.).

Table 3.1. Master thesis project research partners/collaborators list

Research Partners	Purpose and Contributions	Collaborative Chapters
MIT Ideation Laboratory [123]	It helped us frame the right research questions and gave us guidance on the scope of related work for this study, the discussion guide for expert interviews, and user survey result analysis.	Chapter 1. Introduction Chapter 2. Literature Review Chapter 3. Research Methodology Chapter 5. Expert Interviews Chapter 6. User Survey Chapter 10. Discussion and Conclusion
MIT The Engineering Systems Laboratory (ESL) [124]	It provided us with comprehensive and in-depth knowledge on system engineering, system architecture, and system thinking to facilitate the process of curating and merging with human-centered design.	Chapter 1. Introduction Chapter 2. Literature Review Chapter 3. Research Methodology Chapter 4. System Approach Chapter 10. Discussion and Conclusion
MIT AgeLab [125]	It sponsored the entire master thesis project, provided suitable interview and survey participants from MIT AgeLab 85⁺ Lifestyle Leaders Panel [126], and assigned us scientists of gerontology to mentor the study.	Chapter 1. Introduction Chapter 2. Literature Review Chapter 3. Research Methodology Chapter 5. Expert Interview Chapter 6. User Survey Chapter 7. Hybrid Participatory Workshop Chapter 10. Discussion and Conclusion
MIT Media Lab Tangible Media group [127]	It collaborated with Professor Hiroshi Ishii to conduct a four-hour hybrid participatory workshop—Envisioning the Future Footwear for an Aging Population in the MIT course (MAS.834 Tangible Interfaces) in the 2021 Fall semester.	Chapter 7. Hybrid Participatory Workshop
Carnegie Mellon University's School of Design [128]	It gave us strong design-related perspectives and coached the design process from user research, concept ideation, product prototype, and business strategy.	Chapter 1. Introduction Chapter 2. Literature Review Chapter 3. Research Methodology Chapter 6. User Survey Chapter 7. Hybrid Participatory Workshop Chapter 9. Computational Design and Prototype

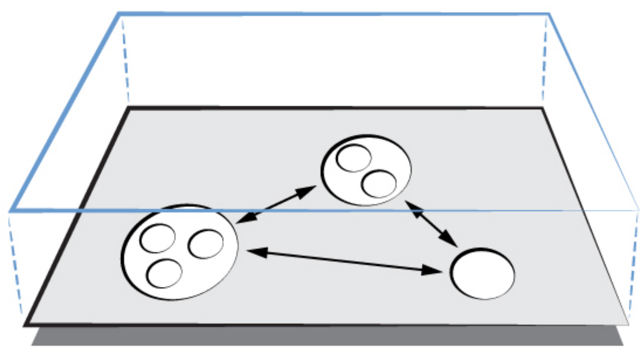
-ing Creatives [129]	It collaborated with us by co-designing a virtual participatory workshop—Rapid Prototyping for Product Design (co-host with Ziyuan Zhu).	Chapter 7. Hybrid Participatory Workshop
Pozyx [130]	It helped us build flexible real-time location systems (RTLS) to identify people's precise dynamic indoor positions and tracking, by using UWB (ultra-wideband) technology	Chapter 8. Assistive Technology
Footwearology [131]	It provided us with a series of online tutorials and material to assist us with gaining skills around building footwear digital models and relevant industry knowledge.	Chapter 8. Assistive Technology Chapter 9. Computational Design and Prototype
nTopology [132]	It supported us with the computation software with the field-driven design feature to translate people's foot-pressure data into three-dimensional coordinates to reconstruct the foam density of a 3D model of a shoe sole.	Chapter 9. Computational Design and Prototype

Chapter 4. System Approach

The study of system engineering (SE) originally started by initiating aerospace-related projects in the 1950s. According to the International Council on Systems Engineering (INCOSE), system engineering is "an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem" [133].

Since then, the SE methodologies and system frameworks have been applied to broader areas of research [110]. For example, some research explored the concept of SE in organizational structure studies, life-cycle analyses, and process innovation to reveal the power of using SE by integrating various disciplines and knowledge [109].

Figure 4.1. Apply system approaches to have a bird's-eye view of targeted systems.
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



In this chapter, we covered three selected system approaches, OPM, ConOps and DSM, to discuss the possibilities of merging them with the DT process.

We used the current indoor footwear product and service design as our analysis subject for the methodology and framework experiments. The aim is to help us 1) have a comprehensive understanding of each indoor footwear element without losing the full picture and 2) set up a solid foundation of knowledge before we start to design the future indoor footwear product and services for older adults.

For further studies, we have prototyped and applied HCSD to parts of this study and other research topics with diverse design challenges by combining and curating system engineering methodologies e.g., ConOps with selected design thinking approaches e.g., user journey map, scenario, in order to extend and enrich the content of Chapter 4 by publishing the following nine conference papers:

- Experimenting with Design Thinking and System Engineering Methodologies [4]

- Apply and Curate the Object-Process Methodology (OPM) and the Human-Centered Design to Solve the Systemic Challenge — Use Campus Tour Experience Design as an Example [29]
- A Systematic Thinking Design Research Approach Combining the ConOps with Design Scenario — Use Commercial Cislunar Space Development Project as an Example [30]
- Applying a System Engineering Approach to the Early Stage of Product Design [26]
- Apply Funnel Model to Design Thinking Process [5]
- An Expert Interview Study of IoT Wearable Technologies for an Aging Population from Product, Data, and Society Dimensions [31]
- Human-Centered System Design for Global Supply Chain [134]
- The Transformation of Design Platform Under System Thinking [135]
- Reshape Safe and Sustainable Makerspaces and Laboratories on Campus: An Experimental Study on Material Flow through Human-Centered System Design [136]

4.1. Apply Object-Process Methodology (OPM) to Analyze an Indoor Footwear System

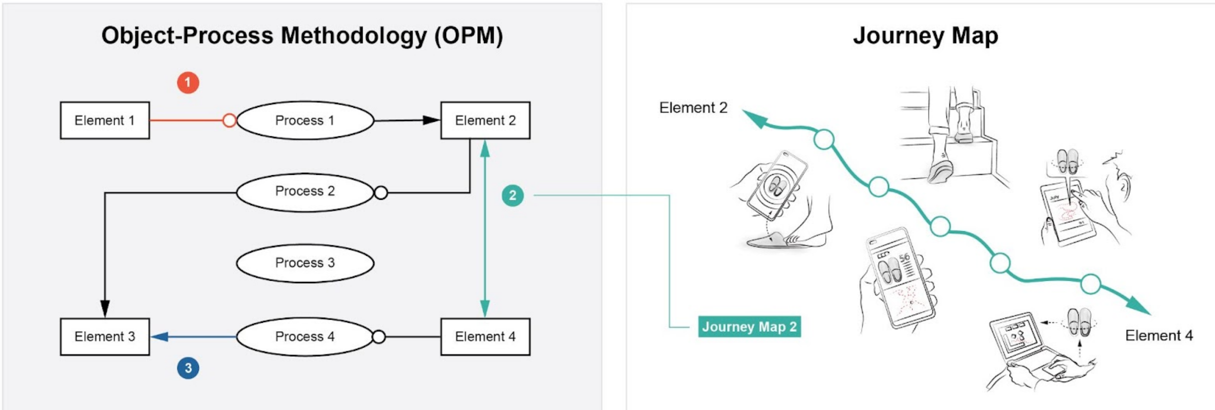
In Section 2.3.1, we applied the OPM approach by following its instruction to define the objects and processes in the indoor footwear system designed for older adults.

We used OPCloud as a helpful and informative web-based prototyping tool to help us build a 2-layered system diagram (SD) of indoor footwear systems as shown in Figure 4.2. [137]. Since OPCloud is a real-time Model-Based System Engineering (MBSE) online software, it made the building process collaborative, transparent, and easy to learn and modify.

OPCloud will also automatically generate the OPM language, OPL, which is not really sentences. But the verbs from OPL can help us understand the relationship between object-to-object or object-to-process or process-to-process by using different types of links e.g., generating, consuming, and attracting (Table 2.1.).

For further research opportunities of the proposed HCSD, we can integrate user journey into each link to diversify the meaning of different types of links and make them exist in the context relevant to our target users (Figure 2.9. and Figure 4.2.).

Figure 4.2. Use indoor footwear design as an example to apply OPM merging with the journey map. (designed by Sheng-Hung Lee)



In this section, we only decomposed the object of the indoor footwear product into two layers of SD. In Figure 4.3., the light blue part indicates how we zoomed into one "object"—an indoor footwear product. Meanwhile, we also highlighted the service (orange oval) and system (green oval) as two key "process" components in both layers of SD.

Figure 4.3. The relationship of the first and the second layers of SDs
(designed by Sheng-Hung Lee)

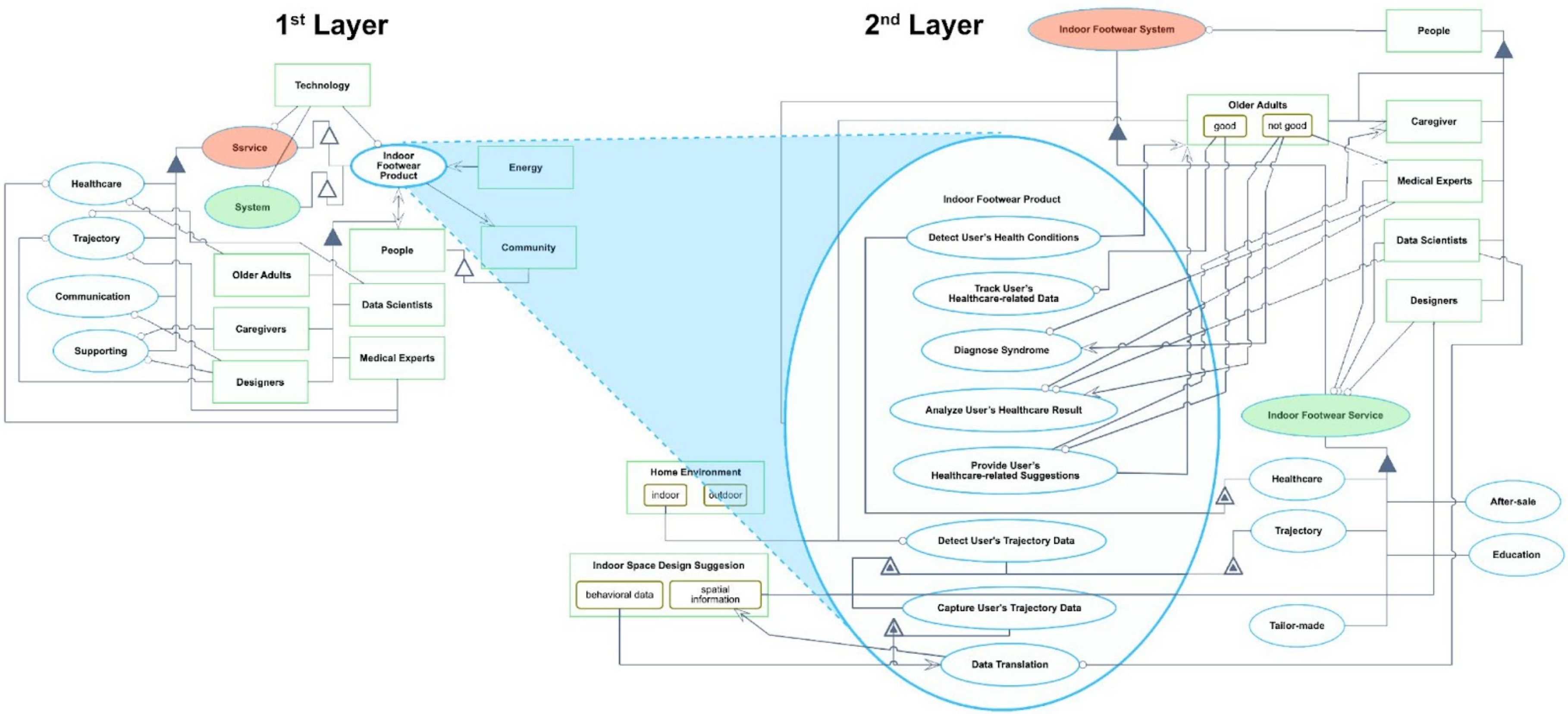
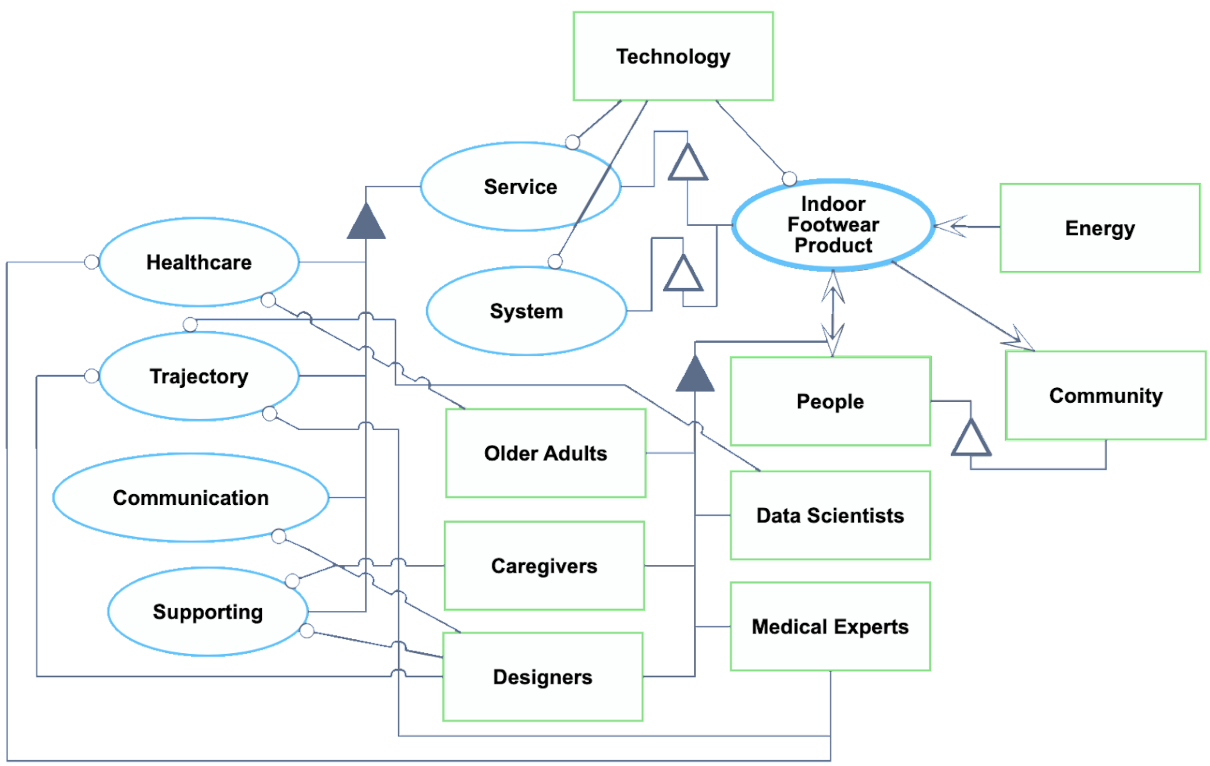


Figure 4.4. shows the first layer of SD. We described indoor footwear as a combination of product, service, and system. We selected six sentences from OPL, which were automatically generated (the verb) by OPCloud to help us understand the idea of using OPM. The purpose of using OPL wasn't for us to read the literal meaning; instead, it was a useful tool to help us check whether we used the right type of links to connect object-to-object or object-to-process. The full version of OPL with 31 lines is covered in Appendix A—OPL.

- OPL line 13: Service **consists of** Communication, Healthcare, Supporting, and Trajectory.
- OPL line 14: People **consist of** Caregivers, Data Scientist, Designers, Medical Experts, and Older Adults.
- OPL line 17: Indoor Footwear Product **affects** People.
- OPL line 18: Indoor Footwear Product **consumes** Energy.
- OPL line 21: Indoor Footwear Product, Service, and System **required** Technology.
- OPL line 31: Trajectory **requires** Data Scientists, Designers, and Medical Experts.

Figure 4.4. The first layer of SD (designed by Sheng-Hung Lee)

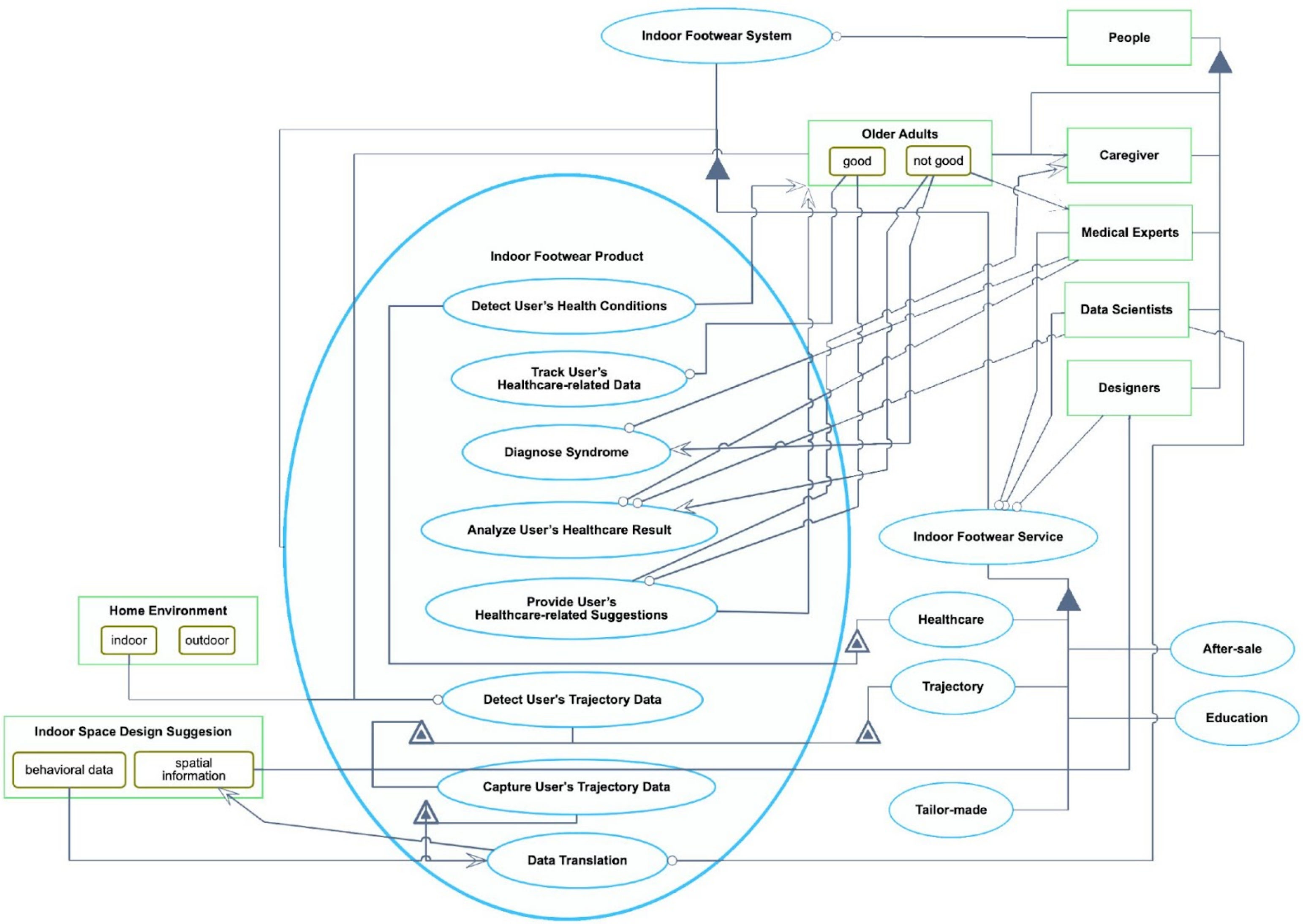


The second layer of SD is shown in Figure 4.5., and we applied a similar decomposing process to the first layer of SD in Figure 4.4. We only experimentally explore the indoor footwear product. Within the product (blue oval), we added eight selected processes that we designed and built to realize the two functions of 1) detecting and diagnosing an older adult's health condition and 2) capturing and translating their indoor walking trajectory and behavioral data into spatial design suggestions for the future. Table 4.2. lists the other seven system-level functions that we envisioned for the future indoor footwear design.

In order to better understand the SD, we also listed six critical sentences of OPL as a reference and the full version of OPL is covered in the Appendix A—OPL.

- OPL line 8: **State** not good of Older Adults **relates to** Medical Experts.
- OPL line 22: Data Translation **exhibits** Capture User's Trajectory Data.
- OPL line 30: Diagnose Syndrome **requires** Medical Experts.
- OPL line 31: Diagnose Syndrome **consumes** Older Adults **at state** not good.
- OPL line 36: Provide User's Healthcare-related Suggestions **requires** Older Adults **at state** good.
- OPL line 49: Data Translation changes Indoor Space Design Suggestion from behavioral data to spatial information.

Figure 4.5. The second layer of SD
(designed by Sheng-Hung Lee)

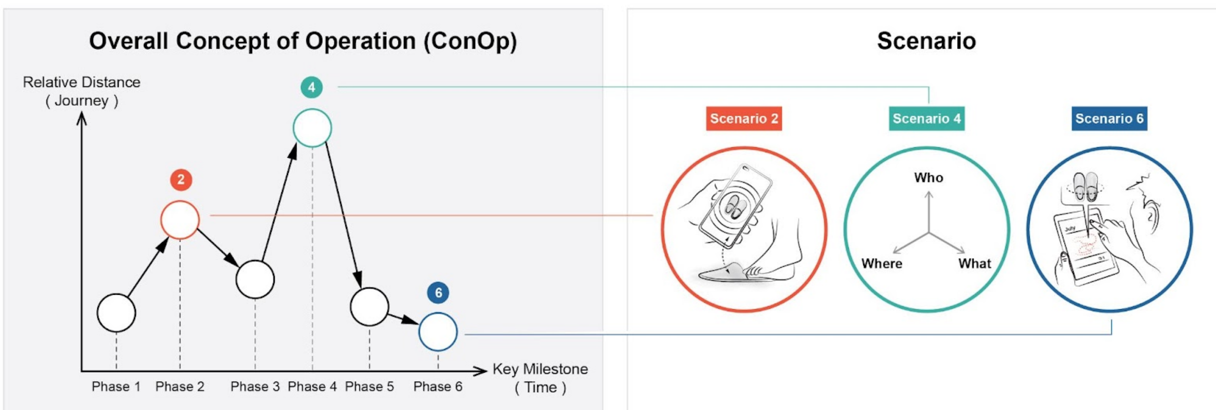


4.2. Utilize Concept of Operations (ConOps) to Illustrate an Indoor Footwear User Scenarios

In Section 2.3.2, the literature review helped us better understand ConOps before we experimentally merged it with the design scenario (Figure 2.11.). We used ConOps to assist the whole project team to have a bird's-eye view of the system roadmap. In this study, we want to paint more colors to each phase of ConOps by illustrating people (who), environment/context (where), and the mission/task that people need to achieve (what).

Adding design scenarios to ConOps enables people to zoom in on each phase of ConOps in detail easily and also ensures that team members can gain more clarity before incorporating their decision-making while facing critical system emergence. Figure 4.6. reveals the first step of the concept sketch.

Figure 4.6. The ConOps merges with design scenario of indoor footwear product, service, experience, and system designed for older adults—1 (designed by Sheng-Hung Lee)



In this case study, indoor footwear user scenarios, we broke down the indoor footwear system ConOps into five phases: 1) Connect people and product, 2) Detect people's in-home trajectory, 3) Capture people's behavior data, 4) Process the relationship of data, and 5) Provide space layout suggestion. And we experimentally merged the three design scenario criteria—who, where, and what—with the five ConOps phases (Figure 4.6.).

Table 4.1. lists the description of each phase in the ConOps in relation to the design scenarios including the key stakeholders/objects (physical and informational) in this scenario, the situations/locations they will face. and the tasks they will finish/solve.

When the key stakeholders of the project (we used indoor footwear in this case) received the information from Figure 4.7. and Table 4.1., it effectively helped them grasp a brief overview of how the system/mission operates and the system-level requirements that they need to prepare and knowledge or skills that they need to acquire for the near-term future within the early specification phase.

Table 4.1. The matrix of ConOps and design scenario

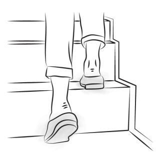
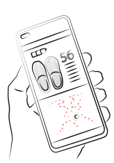
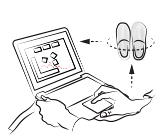
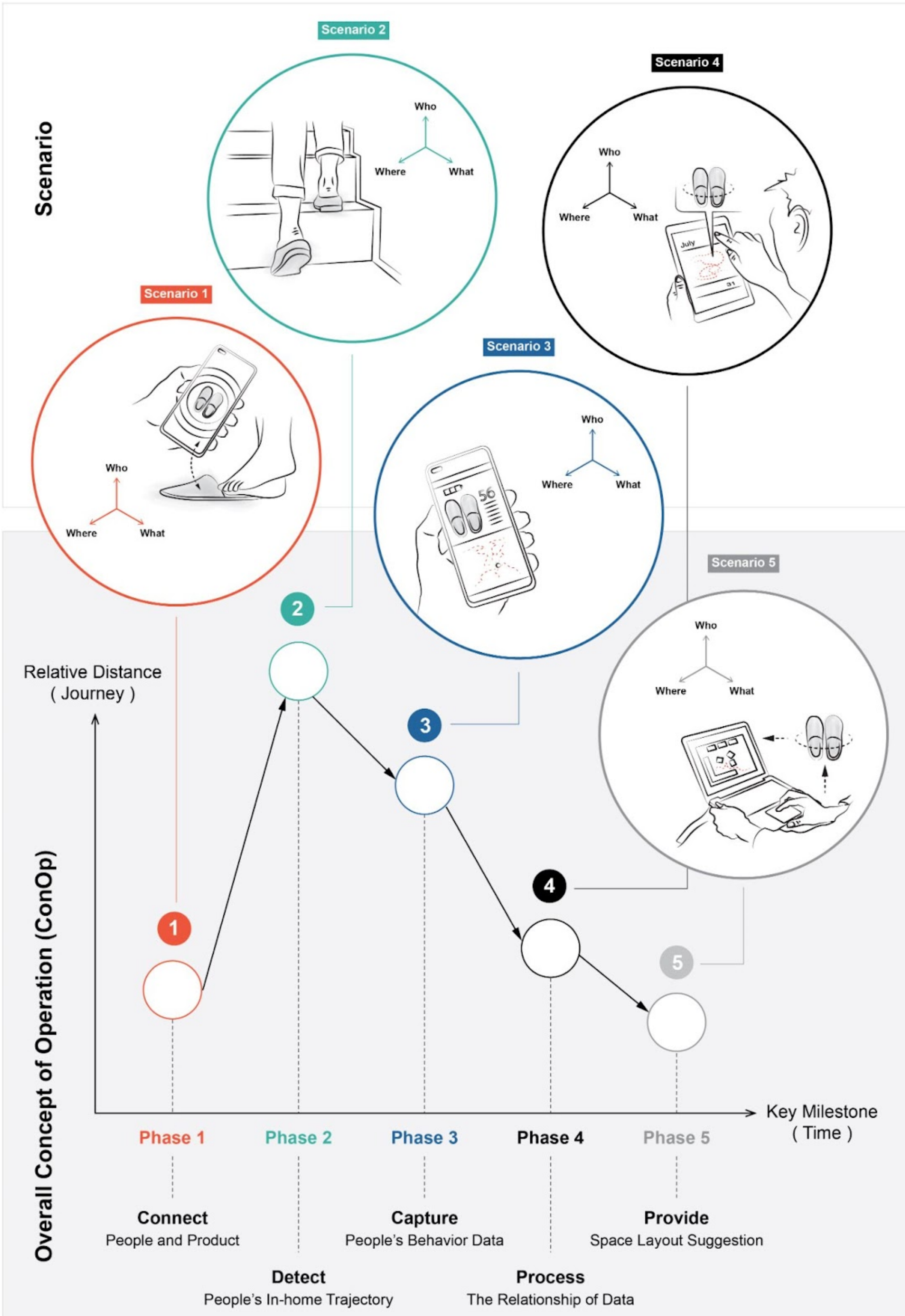
Design Scenario Criteria **ConOps Phase Description**	**Who** *Who are the key stakeholders/objects (physical and informational) in this scenario?*	**Where** *Where are the situations/location they will face/stay?*	**What** *What are the tasks they will finish/solve?*
Phase 1: Connect people and product 	Users (older adults), their caregivers (family, medical team), and indoor footwear kit (footwear, packaging, service, system)	It's most likely to happen at users' homes once they receive the indoor footwear kit package.	The main task is that the users will activate the indoor footwear product and service.
Phase 2: Detect people's in-home trajectory 	Users, indoor footwear, indoor footwear app/service, indoor footwear system	The indoor trajectory detection will occur while the users are moving in their home environment.	Indoor footwear product/app/service/syste m detected and diagnosed users' in-home trajectory.
Phase 3: Capture people's behavior data 	Users, indoor footwear, indoor footwear app/service, indoor footwear system	It includes two parts: indoor footwear app/service and its diagnosis and analysis systems.	Indoor footwear product/app/service/syste m captured, and analyzed users' in-home trajectory.
Phase 4: Process the relationship of data 	Indoor footwear app/service, indoor footwear system, medical team/experts, data scientists, and designers	It covers two sections: indoor footwear app/service and its diagnosis and analysis systems.	Indoor footwear product/app/service/syste m processed and displayed users' in-home trajectory.
Phase 5: Provide space layout suggestion 	Users, indoor footwear app/service, designers, data scientists, medical team/experts, architects, and landscape planners	The analysis and recommendation process was conducted through the indoor footwear app/service.	The result is to provide suggestions regarding space/interior design based on users' behavior, lifestyle, ritual, and interaction with others who live together.

Figure 4.7. Merge ConOps with design scenario of indoor footwear product, service, experience, and system designed for older adults—2 (designed by Sheng-Hung Lee)



4.3. Use Design Structure Matrix (DSM) to Decompose an Indoor Footwear System

The DSM decomposition process can be categorized into four steps suggested by Professor Steven D. Eppinger, MIT Management Science and Innovation: 1) decompose the system, 2) analyze the system DSM, 3) identify the change propagation, and 4) review the results.

Regarding DSM implication, we applied the DSM decompose process to generate nine subsystems to describe the indoor footwear system based on product functionalities/features e.g., product, energy, communication, community, healthcare, supporting system, and people (Table 4.2.). In general, there can be many versions of subsystem names to describe the whole system, depending on the level of resolution that we want to have. However, Table 4.2. was a version we felt had suitable fidelity to go with and we put it into a 49 x 49 Design Structure Matrix (DSM) shown in Figure 4.8.

Table 4.2. Indoor footwear DSM sketch

Subsystem	Component description	Subsystem	Component description
PRODUCT	• Device design • Device manufacturing • Device upgrading • Device recycling • Device technology • Device business model • Device marketing position	**HEALTHCARE**	• Detect user's health conditions • Track user's healthcare-related data • Diagnose syndrome • Analyze user's healthcare result • Provide user's healthcare-related suggestions
ENERGY	• Consume energy from a device (e.g., in-use mode) • Save energy from a device (e.g., sleeping mode) • Recharge a device • Self-generate energy to a device	**SUPPORTING**	• Device structure supports • Device material/texture supports • Device ergonomic supports • Device technology supports • Device assemble supports
COMMUNICATION	• Contact families and friends. • Contact doctors and hospitals. • Interact with a device (e.g., user interface) • Connect with other APP-based or phone-based device	**SYSTEM**	• System landscape • System upgrades • System maintains • System feedback loop • System transfers • System connects • System shutdown
COMMUNITY	• Build social networks • Shape community culture • Form meaningful community relationships • Cultivate community ritual	**SERVICE**	• Device ordering service • Device delivering service • Device tailor-made service • Device recycling service • After-sale service • Education service • Training service • Self-diagnose service • Professional medical service
		PEOPLE	• User's behavior of using a device • User's perception of using a device • User's preference of choosing a device • User's lifestyle/pattern

In Figure 4.8., the upper left figure demonstrates the list of nine subsystems (color-coded aligned with Table 4.2.) and how they react to each other in the footwear system. The lower left table provides more detailed views of each subsystem. Starting from viewing footwear as a whole system, we can deconstruct footwear design into nine subsystems: product, energy, communication, community, healthcare, supporting, system, service, people.

One of the key findings was that after using DSM decomposition, our original groupings were still partially connected depending on our criteria, and most original clusters have other new elements (groups) next to them.

Since we color-coded each component in the subsystem (Table 4.2.) before applying DSM, we can compare the analysis result easily by seeing the color difference. For example, in Figure 4.8. the roll AF (system maintains), AG (system feedback loop), and A (device design) were clustered in the same group, which meant we had two components' text in yellow (SYSTEM) and one component text in black (PRODUCT). We can indicate that when we consider the cluster of SYSTEM, we also need to think about the component of PRODUCT.

Interpreting the result informed us that the initial hypothesis probably was not as comprehensive as we thought or we needed to consider different ways of establishing our criteria. Either of these scenarios indicated that DSM was a great tool to enable designers or researchers to re-consider the new possibilities to look at the systems.

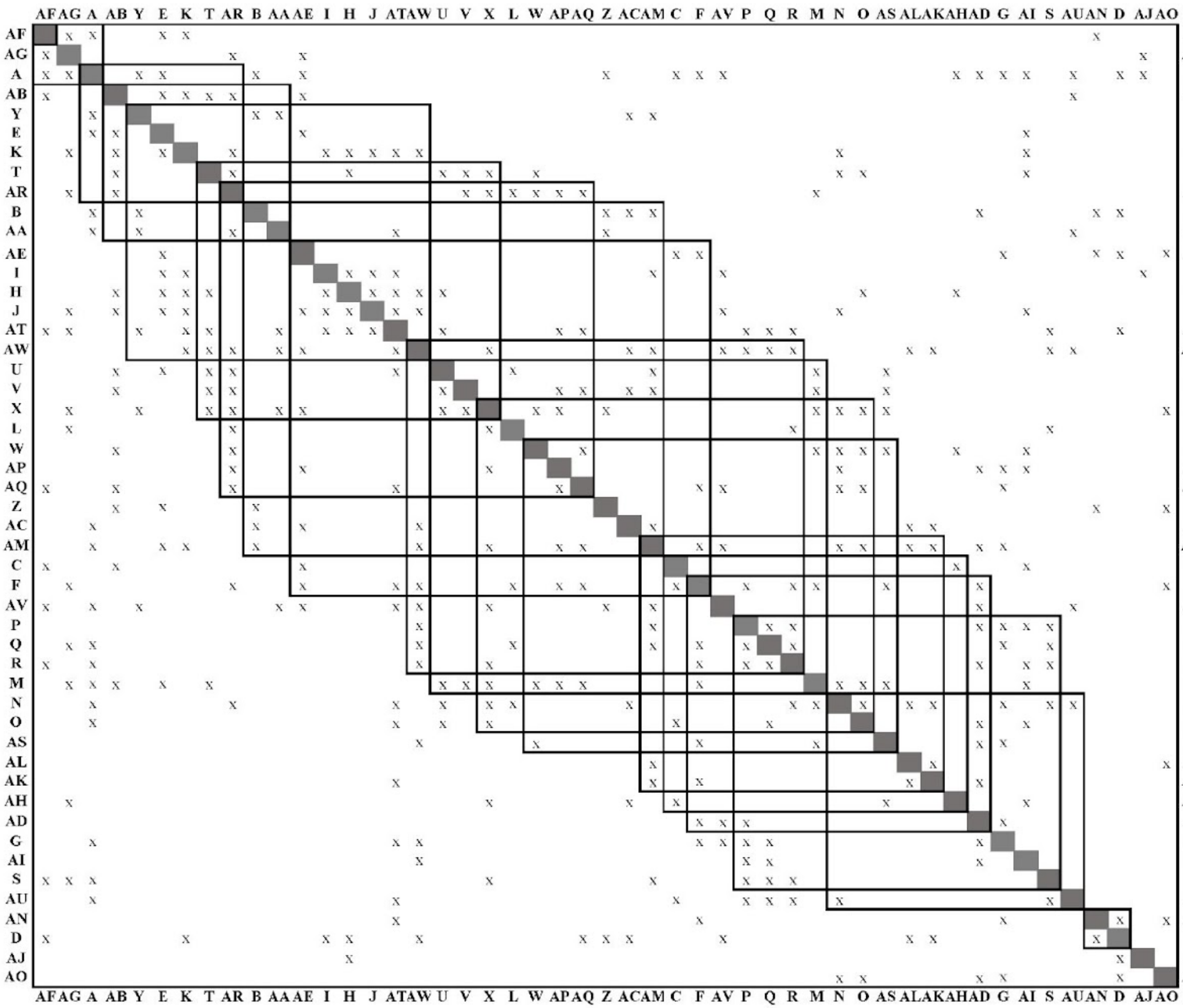
Applying the DSM to distill the nine subsystems helps design team and researchers to structurally organize the relationship between each component in the system to clarify each component's forms, functions, and design intention. Further, design teams can identify their desirable features to interact with our targeted stakeholders which include senior people (care recipients), family (caregivers), medical team (doctor), service provider (company), and product team (designers and engineers).

We can also try to categorize the footwear design system based on user's behavior, emotions, business strategy, manufacturing cost, or other key factors to compare the difference using the criteria of product functionalities/features to experiment with how to extend the result and the influence of DSM. Ultimately its process and outcome reduce the emergence (some unexpected incidences) of the system.

Meanwhile, we need to consider the size of the DSM carefully. Since the number of rows and columns are the same to compose a square matrix, we need to clearly define the name of each subsystem or component and how each subsystem or component interacts reasonably in a real-world context with much uncertainty and other complicated factors. In short, the larger the matrix, the more challenges to do analysis and cluster it afterward.

We were informed that this part of the research was published in MIT AgeLab Connected Home Logistics Consortium (Project C3) research notes—Applying the Design Structure Matrix (DSM) for the design of an in-home wearable solution—by the project sponsors: AlerisLife, Humana, Adventist Health, Five Star Senior Living, Stanley Healthcare, Best Buy, Lowe's, Kohler, USAA, Ups, and WeHealth in November 2021 [138].

Figure 4.8. DSM of Indoor Footwear Design



- AF SYSTEM: System maintains
- AG SYSTEM: System feedback loop
- A PRODUCT: Device design
- AB SUPPORTING: Device technology supports
- Y SUPPORTING: Device structure supports
- E PRODUCT: Device technology
- K ENERGY: Self-generate energy to a device
- T HEALTHCARE: Detect user's health conditions
- AR SERVICE: Self-diagnose service
- B PRODUCT: Device manufacturing
- AA SUPPORTING: Device ergonomic supports
- AE SYSTEM: System upgrades
- I ENERGY: Save energy from a device (e.g., sleeping mode)
- H ENERGY: Consume energy from a device (e.g., in-use mode)
- J ENERGY: Recharge a device
- AT PEOPLE: User's behavior of using a device
- AW PEOPLE: User's lifestyle/pattern
- U HEALTHCARE: Track user's healthcare-related data
- V HEALTHCARE: Diagnose syndrome
- X HEALTHCARE: Provide user's healthcare-related suggestions
- L COMMUNICATION: Contact families and friends.
- W HEALTHCARE: Analyze user's healthcare result
- AP SERVICE: Education service
- AQ SERVICE: Training service
- Z SUPPORTING: Device material/texture supports
- AC SUPPORTING: Device assemble supports
- AM SERVICE: Device tailor-made service
- C PRODUCT: Device upgrading
- F PRODUCT: Device business model
- AV PEOPLE: User's preference of choosing a device
- P COMMUNITY: Build social networks
- Q COMMUNITY: Shape community culture
- R COMMUNITY: Form meaningful community relationships
- M COMMUNICATION: Contact doctors and hospitals.
- N COMMUNICATION: Interact with a device (e.g., user interface)
- O COMMUNICATION: Connect with other APP-based or phone-based device
- AS SERVICE: Professional medical service
- AL SERVICE: Device delivering service
- AK SERVICE: Device ordering service
- AH SYSTEM: System transfers
- AD SYSTEM: System landscape
- G PRODUCT: Device marketing position
- AI SYSTEM: System connects
- S COMMUNITY: Cultivate community ritual
- AU PEOPLE: User's perception of using a device
- AN SERVICE: Device recycling service
- D PRODUCT: Device recycling
- AJ SYSTEM: System shutdown
- AO SERVICE: After-sale service

4.4. Lessons Learned from System Approaches

Under the topic of HCSD, there were many things and processes we can learn from curating and integrating the DT process with SE in terms of its application, adaptation, and benefit to academia and industry. From the literature review, we can understand that HCSD is not a novel idea. Experts and researchers have agreed upon many different interpretations of this framework from the various domains of knowledge to illustrate how we understand the world and things around us.

We also want to acknowledge that creating or using HCSD is more than a methodology shift. It's also a mindset change for researchers, design practitioners, and educators who are in the process of using HCSD. We used the summary of this chapter to explore and expand part of our research questions from Section 1.2., under the research direction 1—HCSD methodology:

- How do we define HCSD methodology concisely by refining traditional HCD processes (focusing on product design) and integrating SE and SA methodologies?
- How do we precisely translate ideas and concepts inspired and contributed by participants through using HCSD methodology from inspiration to ideation to implementation to reflect the desirability of people, the feasibility of engineering, and the viability of the business?

4.4.1. Key Learnings and Discussion

1) Use system approaches to view things as systems.

"System thinking is not thinking systematically. System thinking is to view things as systems," said Professor Edward Crawley from MIT Department of Aeronautics and Astronautics [107]. His view of system thinking should help researchers, designers, and engineers make these complex systems appear less complicated.

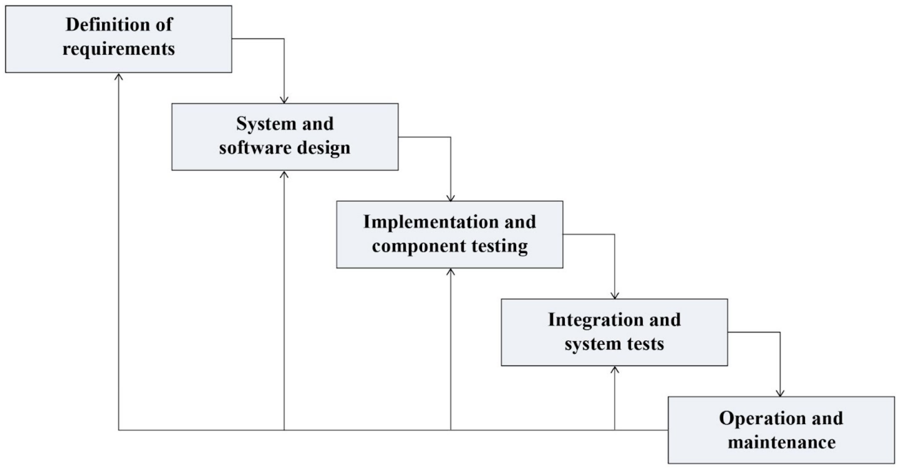
We kept this critical principle of system thinking in mind, especially when we applied OPM, ConOps, and DSM to this thesis project. We decomposed regular things, in this case, we used indoor footwear design for older adults, and broke them into pieces of elements within the system to observe how each element interacted to form relationships.

Using system approaches does not mean making the process of solving design challenges more complicated and hard to understand. Instead, applying OPM can help us to clarify who the key stakeholders in the systems are to identify pain points and opportunity areas.

2) Bridge the gap between the participation of key stakeholders and the development of systems in the early stage of the design.

From the literature review and research, we found that there is a gap between the participation of key stakeholders and the development of systems. For example, the waterfall model (Figure 4.9.), the well-known process model for system design and development, provides the participatory phase for end-users and other key stakeholders to share their needs only in the startup phase [106]. The SIMILAR process (Figure 4.10.) is another system model that puts the stakeholder needs in the center of the diagram starting with their needs to design solutions [139].

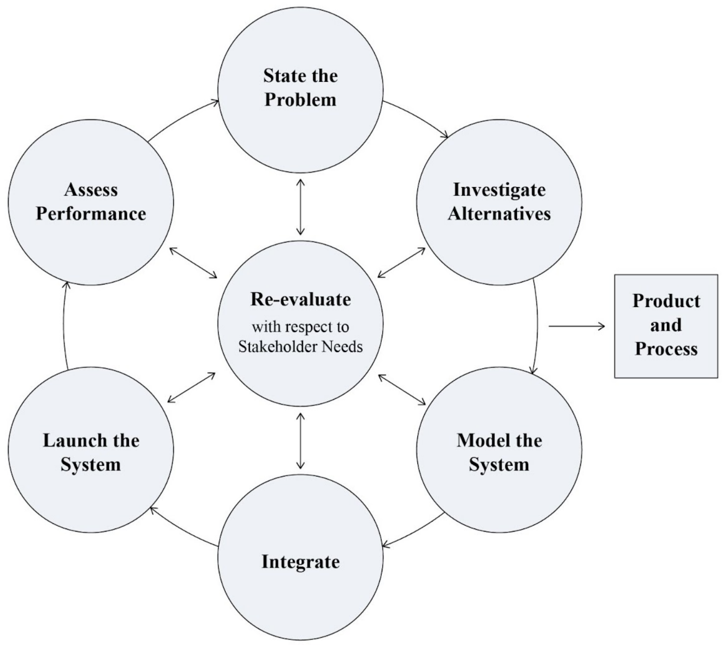
Figure 4.9. The waterfall model with iterations
(the diagram was adapted from the book—Systems Engineering: Systems Engineering: Fundamentals and Applications [106])



In the study, three SE methodologies–OPM, ConOps, and DSM–were used to integrate with DT to form HCSD; we were experimenting to consider a phase to receive users' feedback. But most of the time, designers or engineers have made key decisions as a team without thinking empathetically about the needs of key stakeholders in the systems: leadership, suppliers, acquirers, customers, sponsors, manufacturers, the government, operators, and others. Further exploration and designing of HCSD can focus on how to effectively leverage the benefit of key stakeholders' feedback during system development.

Figure 4.10. The SIMILAR process

(the diagram was adapted from the book—System Design and the Design Process [139])



<u>3) There is no perfect HCSD methodology.</u>

After conducting three SE and SA frameworks and methodology prototypes, we found that there is no perfect methodology that can solve all social-technological challenges. DT and SE/SA are complementary approaches with different features; some fit for qualitative research (e.g., user interviews), and others are suitable for quantitative research (e.g., data collection).

They also contain context-driven features (e.g., different types of design challenges) that might change how to apply them or portions of them in different sequences. In further studies, we need to consider the role of more criteria (e.g., the adaptability, modularity, and feasibility) in HCSD to make this framework useful and meaningful [104].

<u>4) Consider the solution at a system-and-service level of indoor footwear design beyond the product innovation.</u>

Throughout the study of system approaches and HCSD research, the aim of the case study of designing indoor footwear for older adults lay in creating a sustainable system considering the desirability of people, the feasibility of the technology, and the viability of the business to connect products, services, and experiences [80, 82]. The indoor footwear product was one of the elements within the system.

Without building a robust and responsive platform, it is hard to make the products and services of indoor footwear design successful and impactful to deliver the human-centered experience to our target care recipients and caregivers. Therefore, using HCSD and system approaches in the indoor footwear design, we aimed to come up with solutions covering the perspectives of people, products, and platforms.

4.4.2. Further Studies

1) Explore the boundary of using HCSD and define its success matrix.

We experimentally tested using HCSD on various research topics from curriculum design, to campus tour design, laboratory building design, sustainability challenges, and indoor footwear product and service design. We were curious to know the limitations of using HCSD. What types of research topics (e.g., product innovation, service design project, or experience design project) are suitable for applying HCSD? How do we evaluate the success of projects while using HCSD? What are the criteria to measure the effectiveness of using HCSD?

2) Select other methodologies or framework merging with DT.

In the study, we selected OPM and ConOps as typical methodologies from SE. This enabled us to further consider what other approaches or frameworks from SE or SA we can merge with DT and conduct experiments with (e.g., Six Thinking Hats (STH), SWOT Analysis, Focus Groups, Plus-Minus-Interesting (PMI) Analysis, Morphological Analysis, Decision Tree Analysis, Value Analysis (VA), Pareto Analysis, Kano Model Analysis, and others). For further research, we can establish a methodology or framework library providing a series of suggested options from SE, SA, and DT.

3) Optimize the benefit of using system approaches to design products and services, instead of viewing them as analysis tools.

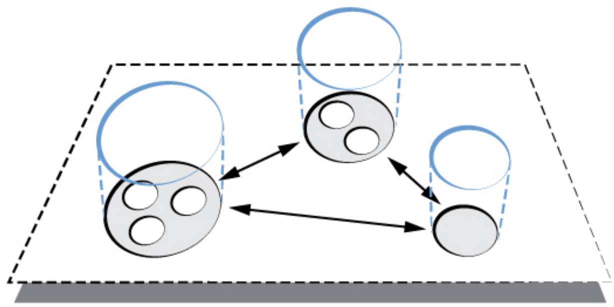
We used system approaches to analyze current indoor footwear product and service design to give us a better understanding of the whole picture of the system. It is a straightforward process to analyze our target object: indoor footwear design. Besides applying the system approaches as a useful analysis tool, in future studies, we can integrate system approaches into the creative journey starting from the design phase by leveraging system approaches to co-create an innovative product and service design.

Chapter 5. Expert Interview

After using system approaches in Chapter 4 to holistically view the research topic: designing indoor footwear for older adults using HCSD, we wanted to integrate the voices of experts from the industries to complete the study.

Therefore we invited 31 experts from various industries to discuss their unique perspectives about IoT wearable devices, indoor footwear design for older adults, and data-related issues: privacy, sensitivity, security, and application. The recruitment of the expert interviewees was through personal connections and recommendations from the selected design professionals and design academics.

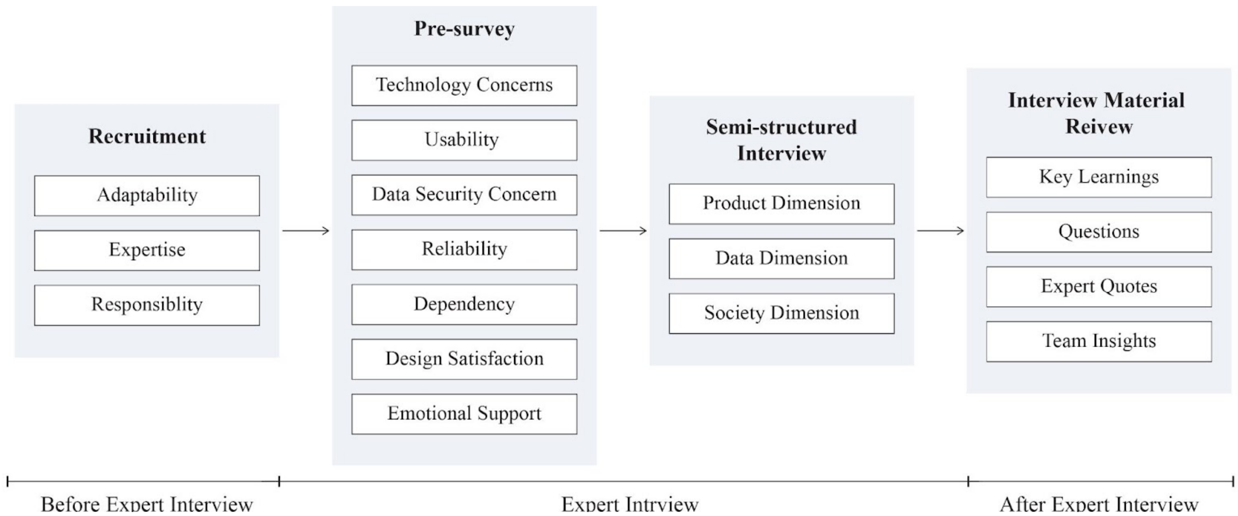
Figure 5.1. Zoom in to the system by interviewing experts and users.
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



Each 45-minute expert interview was conducted online, paired with a 3-minute pre-interview survey. We documented our learnings on the pre-designed interview capture sheets with seven items: 1) background information 2) pre-interview result 3) key takeaways 4) key quotes 5) inspirational ideas 6) potential further research themes and 7) ARE evaluation framework. The overall structure and flow of the expert interview is shown in Figure 5.2.

We addressed some parts of the content in Chapter 5 to publish the conference paper, An Expert Interview Study of IoT Wearable Technologies for an Aging Population from Product, Data, and Society Dimensions at the Human-Computer Interaction (HCI) International 2021 [31].

Figure 5.2. Expert interview flow and key consideration
(the diagram was adapted from the published conference paper [31])



We appreciated all 31 experts who participated in interviews for the research. Some of their insightful quotes were adjusted to fit the written format under their permission but the content remained the same message they wanted to share. Their perspectives of IoT, technology, or design didn't represent the companies they worked for. The expert interview was conducted for the purpose of academic research and stayed neutral.

5.1. Expert Interview Preparation and Process

Due to the pandemic, we conducted the expert interviews for the research online, which made the interview preparation and process different and much more important than typical in-person interviews. We needed to consider the overall interview experience: What is the interview participants' attention span on average per online meeting? How do we design engaging sections to break the ice, since we had not met most of the expert interviewees in person beforehand? How do we immediately build trust before/during the interview, so that our interviewees can feel safe to share their insightful thoughts, especially since we asked for their permission to record the entire interview section? These were all logistical details, which would make a significant difference in helping us execute the interviews efficiently and effectively.

In Section 5.1., we describe the design of the expert interview capture sheet (Figure 5.3.) we used for our discussion with 31 experts from various fields. A detailed explanation of each of the sheet's seven items is as follows. Each expert interview note is documented in Appendix E—Expert Interview Notes for further studies.

Figure 5.3. Expert interview capturing sheet with seven items
(illustrated by Sheng-Hung Lee)

1) Background information

We prepared by studying their information including educational background, expertise, current position, and previous working experience prior to each expert interview. This also helped us confirm that we recruited the right expert candidates for this study.

2) Pre-interview result

We invited each of our expert interviewees to fill out a 3-minute online pre-interview survey before the 45-minute interview. We also used the pre-interview survey as an ice-breaker to start a conversation with our interviewee.

The intention was to design pre-interview survey questions to get a sense of the respondents' familiarity and comfort level with IoT devices. The survey consisted of 2 single-choice questions (e.g., score the level of automation and comfort), 2 multiple-choices questions (e.g., select your preferred features of IoT wearable devices and indoor footwear), and 2 open-ended questions (e.g., fill out the keywords and complete the sentence). The full pre-interview survey design and questions are exhibited in Appendix D—Expert Interview Pre-survey.

3) Key takeaways

With the permission of each interviewee, we recorded all our expert interview sections to help us better document, take screenshots, and notes accurately. During the 45-minute expert interview, we distilled the key takeaways from our notes and discussed them with the team as shown in Appendix E—Expert Interview Notes.

4) Key quotes

Besides capturing the key takeaways, we also selected quotes from our conversations with the experts, which were the direct evidence for our studies. These were not only useful for our research, but also served as a powerful tool when we compared the survey results and interviews with the users. For the purpose of clarity, we modified most interviewees' quotes.

5) Inspirational ideas

During each interview, we followed constructive interview guidance to generate inspiring discussions with the 31 experts. This enabled us to come up with lots of crazy ideas across different scales: product, service, experience, system, and society. We documented either in text or visuals during/after the interview. The purpose was to help us extend our initial ideas beyond considering indoor footwear design only for older adults from beginning to end.

6) Potential further research themes

The topics of IoT wearable devices, indoor footwear design, design for an aging population, product innovation and service design, and human behavior analysis for the expert interviews were very broad and interconnected with many other disciplines. Therefore, we used this opportunity to brainstorm other potential research topics relevant to our studies.

7) ARE evaluation framework

ARE evaluation was an experimental measurement framework that we designed specifically for this expert interview to help us understand the invited experts better through the following three unique criteria: Adaptability—to understand the comfort level of the interviewee when facing IoT products and their challenges; Responsibility—to understand the perception of the interviewee about the ethics of IoT and data-privacy-related issues; and Expertise—to understand how knowledgeable the interviewee is about the IoT industry. The detailed introduction, instruction, and application of the ARE evaluation framework are given in Section 5.1.3.

5.1.1. Expert Interview Objectives

In the expert interview stage, we were in the early stage of the design process. We didn't want to start by focusing on indoor footwear design for older adults, which might limit our thinking and design process. Instead, we broadened the discussion topics with our experts from the level of the platform, product, and people. The intention was to consider the problems from the context of users e.g., older adults, to the features of products e.g., IoT wearable devices. Then we zoomed in on the users themselves as an ending point.

1) Platform level: Define an environment as a complicated platform to enable our design and research in the right context and relevant to our users' needs.

For the platform level, we specifically discussed the environmental space of our study subject's home e.g., older adults' indoor space. We discussed spatial-related issues, including the vibe of the space, lighting, and layout, and some issues that were closely relevant to users' behaviors and life rituals.

2) Product level: Envision IoT wearable product features and user experience through human-centered design.

For the product level, we meant IoT wearable devices and technologies including indoor footwear. We leveraged the outcome of the expert interviews to explore other design possibilities, product features, and the format of interactions with users before we narrowed it down to indoor footwear design for older adults.

3) People level: Analyze people's behavior and interaction between product design and environment to identify users' unmet needs.

Regarding people level, we covered their perception around data privacy, sensitivity, and applications interacting with IoT wearable devices and their environment. How do people's behaviors change because of using IoT wearable devices, or do people create their own new rituals to adapt to new technologies?

We explored this topic through the above three levels: platform, product, and people. It was crucial to help us not limit ourselves to consider the indoor footwear design by effectively integrating these key takeaways into our indoor footwear design for older adults.

Synthesizing from the logic behind how we designed and curated our expert interview questions through the level of the platform, product, and people, we concluded the following three research objectives of our expert interview:

1. Learn, document, and integrate the results of the expert interviews with our user survey results to help us design better indoor footwear for older adults from a holistic view.
2. Emphasize the topic of data privacy, sensitivity, security, and application of the IoT wearable devices and industries to identify and satisfy the users' unmet needs in the shoes of older adults.
3. Broaden the project scope of indoor footwear design for older adults from the level of product innovation, service strategy, and experience design to make positive and meaningful social impact.

5.1.2. Expert Interview Questions

We categorized the expert interview questions into two parts: 1) pre-interview survey and 2) interview discussion guide relevant to our interview flow (Figure 5.2.). Due to the pandemic, each expert interview was conducted online within 45 minutes in a systematic and structural way. Prior to the interview, we invited the interviewee to finish a 3-minute online pre-interview survey to help us gather quantitative data by using the experimental AER evaluation framework (Figure 5.4.), which was introduced in Section 5.1.3.

Since our invited experts were very diverse, from entrepreneurs and consultants to designers, technologists, and educators, we prepared a general discussion guide to help us conduct an in-depth discussion about how they define IoT wearable devices and services according to their industry experience. What are their viewpoints on data privacy, sensitivity, security, and application of IoT wearable devices? How do the IoT wearable devices affect people's behavior, work, and life and in a broader context to our society including policy-making, and organizational transformation caused by the technologies and new services?

We also leveraged the result from the pre-interview survey. After the expert interviewee filled it out, we quickly browsed through the result and identified some interesting findings, e.g., abnormal high scores, and to use their answers as an interview prompt for further discussion.

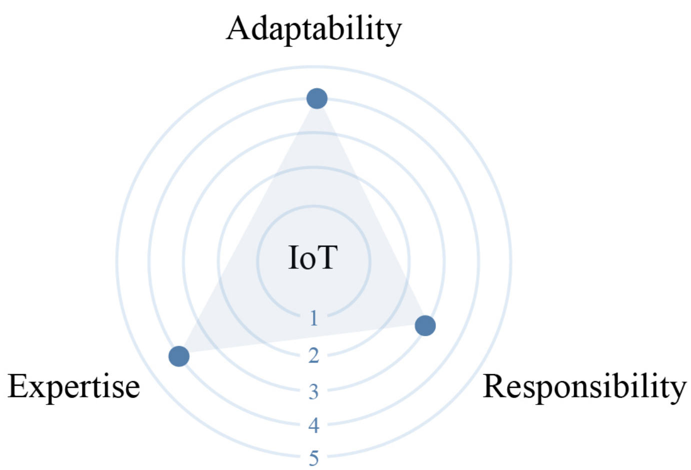
5.1.3. AER Evaluation Framework

When we designed the expert interview pre-survey, we also wanted to have our own measurement matrix—ARE evaluation—to help us better understand our expert interviewee from the aspects of adaptability, expertise, and responsibility (Figure 5.4.). ARE evaluation was an experimental measurement framework and it was still at the early stage of the framework design and development process.

ARE evaluation is a subjective framework for the research team to conduct a high-level evaluation based on the interviewee's experience, expertise, and story. The three criteria are: adaptability, expertise, and responsibility (Table 5.1.).

We created ARE evaluation based on the discussion with other professional designers, design researchers, research scientists from MIT AgeLab, and the author's industry (design and research-related) working experience. We encapsulated the thinking process in Table 5.1. to explain the measurement criteria. The goal of applying this work-in-progress framework was to prototype whether the three measurement criteria were effective to be integrated into our expert interview results.

Figure 5.4. One example of using ARE evaluation framework
(illustrated by Sheng-Hung Lee)



<u>1) Adaptability—To understand the comfort level of the interviewee when facing IoT products and their challenges.</u>

Adaptability is about the comfortable level of an interviewee to adapt to a new IoT smart product or service, and the whole new experience that an IoT smart device will bring them. Is an interviewee willing to change his/her behavior to embrace the change from IoT service to work and life?

2) Expertise—To understand how knowledgeable the interviewee is about the IoT industry.

Expertise is about how knowledgeable an interviewee is about relevant IoT smart product design experience. Some interviewees have IoT product design experience and the capability for IoT smart device product development.

3) Responsibility—To understand the perception of the interviewee about the ethics of IoT and data-privacy-related issues.

Responsibility is about understanding an interviewee's perception of the ethics part of IoT. Is an interviewee willing to sacrifice his/her personal data privacy for better tailor-made services to make life convenient, optimize his/her life and work schedule, or further increase his/her creativity?

Table 5.1. The explanation of the three criteria of the ARE evaluation framework

Criteria	Explanation	Scale						
Adaptability	To understand the comfort level of the interviewee when facing IoT products and their challenges.	Protective isolation	1 ○	2 ○	3 ○	4 ○	5 ○	Seamlessly integrated
Expertise	To understand how knowledgeable the interviewee is about the IoT industry.	Consumer's angle	1 ○	2 ○	3 ○	4 ○	5 ○	Expert's perspective
Responsibility	To understand the perception of the interviewee about the ethics of IoT and data-privacy-related issues.	Convenience -driven	1 ○	2 ○	3 ○	4 ○	5 ○	Privacy matters

5.2. Expert Interview Result

In addition to documenting the stories and insights from 31 expert interviews, we also analyzed the pre-interview results by breaking them down into four sections: demography, data privacy and sensitivity, smart IoT wearable device, and ARE evaluation result. Thus, the expert interview results were synthesized by combining the pre-interview result with our discussion with all expertes (Figure 5.5.).

We documented the complete expert interview notes in Appendix E—Expert Interview Notes as reference material for further studies, including experts' background information, pre-interview results, key takeaways, quotes, ideas inspired from the interviews, potential further research themes, and ARE evaluation framework results.

Figure 5.5. Expert interview screenshots
(screenshot by Sheng-Hung Lee under the permission of interviewees)

5.2.1. Demography

Since the expert recruiting was through personal connection, we weren't aware of the gender balance in advance. Therefore, we had 81% male and 19% female. Regarding experts' backgrounds, they came from diverse industries with different roles and responsibilities: 18% were technological entrepreneurs, 24% were in leadership roles, 18% worked for design/creative consultants, 16% were designers, 4% technologists, 16% educators, and 4% extreme users (Table

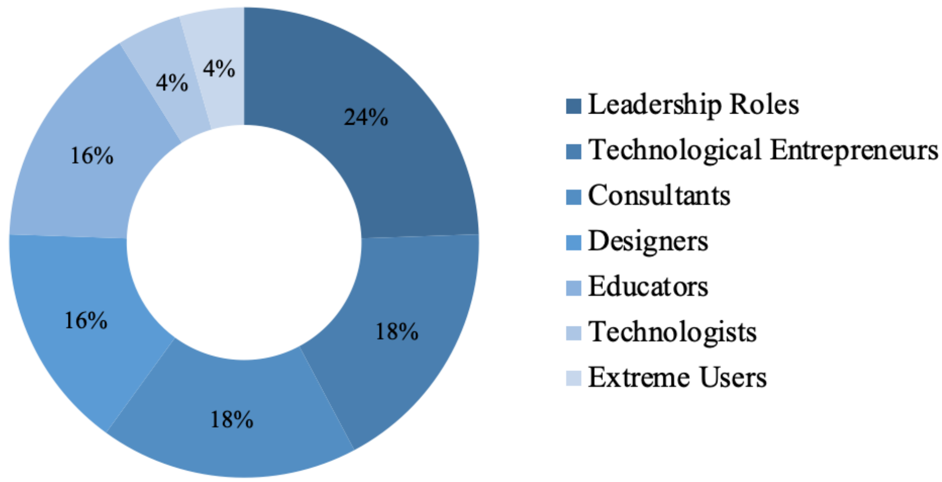
5.2.). In this study, we defined extreme users as a type of expert. We summarized the demography of the expert interviewees in Figure 5.7.

Table 5.2. The demography of expert interviewee

Number of participants	n = 31
Participants' backgrounds	• Leadership roles (24%) • Technological entrepreneurs (18%) • Consultants (18%) • Designers (16%) • Educators (16%) • Technologists (4%) • Extreme users (4%)
Gender	Male 81% Female 19%

Figure 5.6. Selected companies' logos that expert interviewees work for

Figure 5.7. Interview participants' backgrounds



5.2.2. Experts' Attitude toward Data Privacy and Sensitivity

One focus of the pre-interview survey was people's perceptions of data privacy, sensitivity, security, and implications. We assumed this would influence the way we envision indoor footwear for older adults in the future. Technology might change people's behavior through IoT wearable devices. We can think of data as the currency of technology shaping how we think of IoT wearable device design, which also depends on different culture contexts e.g., Western countries versus Estern countries.

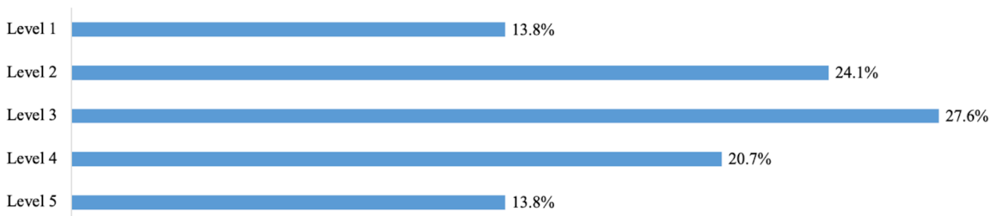
Jerome Goh, Design Lead at IDEO, Adjunct Assistant Professor at Newschool, talked about the concept of using data was very different in China and the US. In China, most people didn't have an option. There was no transparency in terms of personal privacy. In order to have life convenience, people need to sacrifice part of their personal info by using WeChat, which was a multifunctional app that can pay electric, phone, gas fee, book tickets, share their stories, and communicate with others. He said "Most people know they should protect their data, but the truth is the boat (data security) has sailed a long time ago. People are just trying to protect data, but it is actually out of control already."

Figure 5.8. shows people's comfort levels from 1 to 5 about IoT wearable devices that can store and share their data on the cloud. Level 1 meant that people felt uncomfortable whereas level 5 stood for very comfortable.

Interestingly, the majority of experts selected their comfort level between 2 to 4. Level 1 and 5 hit the same percentage of 13.8%. When we did interviews, some experts specifically said that it was OK if their personal data were captured by IoT wearable devices and shared and stored anonymously. Because they thought if their anonymous data could help improve the performance and user experience of the overall system/platform, they considered it a critical contribution, echoing what one expert (participant 21), Director of Design at American multinational medical technologies corporation, shared "Sharing personal data is OK if I can control the smart device, manage and have options to reveal my information, and there is a real benefit to consumers."

One expert (participant 15), former design lead at a design and consulting firm, said "I prefer to read the newspaper. I mean the physical one since it relatively won't filler out most information I dislike. As for in the digital world, the platforms like social media, which provides you with the information, video, WhatsApp you prefer to read. I am afraid this will make everyone live in their own bubble without the needs for communication in the end." She was concerned that the platform algorithm based on users' data from their preference might cause more serious social isolation.

Figure 5.8. How comfortable are you if IoT wearable device can share your data on the cloud? (level 1: uncomfortable, level 5: very comfortable)



In Figure 5.9., we were curious to know why 53.9% of people choose "maybe" even if their personal data was safe and can improve their quality of life. Was it because being safe didn't mean the users can control or manage their data, or do people have other concerns?

Figure 5.9. If your personal data is safe, would you like to share it to improve your quality of life?

In this pre-interview survey, we probed these selected experts to answer the open-ended question about their perception of using data in the design field. Table 5.3. showed their response to completing the sentence "design with the data is like______." It was impressive to see how these experts use vivid metaphors to fill in the blanks and some experts completed the sentence to express their strong opinions.

One expert said that design with data is "an essential ingredient for intelligence, but hard to trust that it's handled responsibly." Another mentioned that design with data is "knowing your customers in a different way." Someone shared with us that design with data is "tricky and often used to serve a company's needs instead of users." Surprisingly, Jason P. Belaire, Chair at Industrial Designers Society of America (IDSA), one of our interviewees, wrote a short paragraph to express his views about the idea of design with data:

“I think that we as humans are less and less in touch with our own emotions and being. We are a culture addicted to complacency and to a multitude of distractions. Due to the enormity of this issue, we need to learn better ways to collect and extract data that will enable us to develop greater rubrics and or opportunities to identify problems that ‘need solved’ that would not fall into the same category as what marketing entities call innovation. But to actually develop product ‘X’ that is truly different and effective. The more we can understand all aspects of data and all the various touch points, the more that we can develop systems and opportunities for great and more ethical products.”

Another interesting aspect shared by Sebastian Gier, Senior Designer at BMW Group UX Design and Founder of Designdrives “Design with data is like a generative design. You don’t know the actual outcome and it is unlike furniture design that designers can predict the result once we have an idea. Design with data normally could generate unpredictable results unexpectedly.”

The topic also triggered some experts to discuss the transparency of data. “Personal data has already been exposed since I pay tax to the government every year. There is no point to worry about using your credit card and afraid of the government tracking your transaction.” said Michael Held, Director Design Global at Steelcase.

After we synthesized the pre-interview survey responses in Table 5.3., it helped us develop a more in-depth understanding of the experts’ perspectives, which assisted us to build more empathy for the users.

Table 5.3. Design with data is ____________________ (complete the sentence).

Response (n=31)	
People’s feelings ● art ● finger painting ● peanut butter and jelly ● making music from noise ● a big menu with a lot of dishes ● questionable in terms of accuracy ● a pairing of complexity and convenience **Strengths and perceptions** ● insightful ● convenience ● helping to explore my real self ● designing with meaningful information ● knowing your customers in a different way ● educating yourself by trying to predict the future	**Limitations and potential** ● as yet underutilized ● difficult and ungainly ● tricky and often used to serve a company’s needs instead of a user’s ● should have community, or scalable benefits, building on mesh network communication ● an essential ingredient for intelligence, but hard to to trust that it’s handled responsibly ● any other kind of design: you have to understand your customer and you must have a vision. Data alone will not yield great products and services. **Structured process** ● generative design ● constant iteration ● prototyping with paper ● designing with your person in the loop ● the fundamental approach to design today

Outcomes and benifits
- predicting behaviors
- offering many options
- more efficient market research
- respond precisely to the users' need

5.2.3. Experts' Attitude toward Smart IoT Wearable Devices

Before we dived into the topic of smart IoT devices, we probed the question to understand experts' perceptions of the smart homes described in two to three keywords, which also helped us with how we positioned the smart IoT device in context. Table 5.4. shows the response of 31 experts that we interviewed.

This was not an easy question. One expert (participant 14), Vice President of Design at Danish high-end consumer electronics company, said "The IoT is a broad term that becomes almost a meaningless label because it can mean everything. The term 'smart home' is definitely a cliche word. People recognize the term but don't understand its meaning."

Another interviewee (participant 10), advisor at the leading global footwear brand labs, shared with us his definition of a smart home, containing two concepts: Smart and Connected. "A smart home means devices or services are helpful whereas a connected home means people's information and data are tracked. But the concept of smart and connected should go hand in hand. It's an interconnected relationship."

From the pre-interview survey result, we found a few words that experts mentioned frequently such as connected, convenience, helpful, seamless, integrated, intelligence, surveillance, communication, and connected devices. Unsurprisingly, a majority of the experts discussed this topic from the perspective of technology, data, and information. What we thought could be missing were more opportunities to explore this topic through the human-centered lens e.g., people's behavior, their ritual in life at home, echoing what one expert shared, "The word smart home sounds a little cold for some reason. It is too logical, not emotional."

Gordon Bruce, Owner of Gordon Bruce Design, also mentioned "Smart home is designed to enhance people's understand of the environment; smart home is like tasks and tools to make people easier to understand their needs to improve human behavior; smart home is designed to satisfy people's daily ritual, and this should be integrated to their daily life." He thought that different countries have different rituals, because of their respective cultural context. Designing smart home for them should follow their own life ritual.

Table 5.4. What comes to your mind when we mention "Smart Home"?
(n means number of keywords shown)

Keywords	n	Keywords	n
● connected	4	● automation	1
● convenience	3	● adaptability	1
● helpful	2	● information	1
● seamless	2	● still around	1
● integrated	2	● automated	1
● intelligence	2	● big brother	1
● surveillance	2	● interaction	1
● communication	2	● interactive	1
● connected devices	2	● exploitive	1
● self-learning residential electronic products, as a system or individual	1	● technical	1
● automatically doing things for me while still protecting my privacy	1	● available	1
● connected products solving problems	1	● Eye Gaze	1
● potentially confusing and frustrating	1	● potential	1
● sound a little cold for some reason	1	● intuitive	1
● less burden on the environment	1	● complex	1
● too logical, not emotional	1	● unsecure	1
● new work possibilities	1	● magical	1
● facilitate house work	1	● latency	1
● things are connected	1	● efficient	1
● smart commuting	1	● security	1
● voice command	1	● comfort	1
● energy efficient	1	● reactive	1
● privacy issues	1	● sensors	1
● early adopters	1	● health	1
● Google home	1	● Alexa	1
● complicated	1	● data	1
● convenience	1	● ritual	1
● atmosphere	1	● speed	1
● customized	1	● utility	1

In the pre-interview survey, we tested experts' comfort level with using smart IoT wearable devices at home. We defined the scale from one to five: level 1 stands for automation of everything and level 5 limited automation. Figure 5.10. shows that 34.5% of experts selected level 4, whereas 0% chose level 1; 20.7% preferred level 5.

We were curious about why no experts chose level 1. Was it because the experts didn't trust the system built for IoT wearable devices? Was it because the source of the smart system comes from people's data, which made them feel uncomfortable about the lack of privacy? Or maybe like Jason P. Belaire, Chair at Industrial Designers Society of America (IDSA), said "IoT products can easily predict people's daily behavior, movement, and trajectory, but it's hard to read people's minds. The time of "I know what you think" is yet to come." David Patton, Vice President of Product Design at Vari, also shared with us the similar perspective "Even though the future of the IoT industry is limitless with huge potential for the application and its service, IoT products are not necessarily smart and do not always understand consumers' needs."

Regardless of the level of automation of smart IoT smart devices that people want to have, people need absolute authority to control their smart IoT wearable devices to some degree, which tied to what expert (participant 10), advisor at the global leading footwear brand labs, said "I only want my IoT product to show the things, the functions that you (the product) promise. And I don't want any surprise."

This aligned with what we found that people as users want the ability to shift into different modes (more than two) from full auto mode to manual mode. Smart IoT wearable devices can provide multiple modes to allow users to change based on their needs. After synthesizing the discussion from the expert interview, we summarized that control provides people with a sense of safety and stability, and thus presumably generates trust.

Figure 5.10. How smart of IoT wearable devices do you feel comfortable to have? (level 1: automation of everything, level 5: limited automation)

Besides analyzing the experts' comfort level with automation of IoT wearable devices, we wanted to know experts' expectations regarding different functions of IoT wearable devices that can assist them at home (Figure 5.11.).

Among the eight options for this pre-interview survey question, the top three choices were: make life convenient (75.9%), improve work efficiency (62.1%), and increase creativity (62.1%). It was interesting to see that most experts wanted IoT wearable devices to make their life convenient.

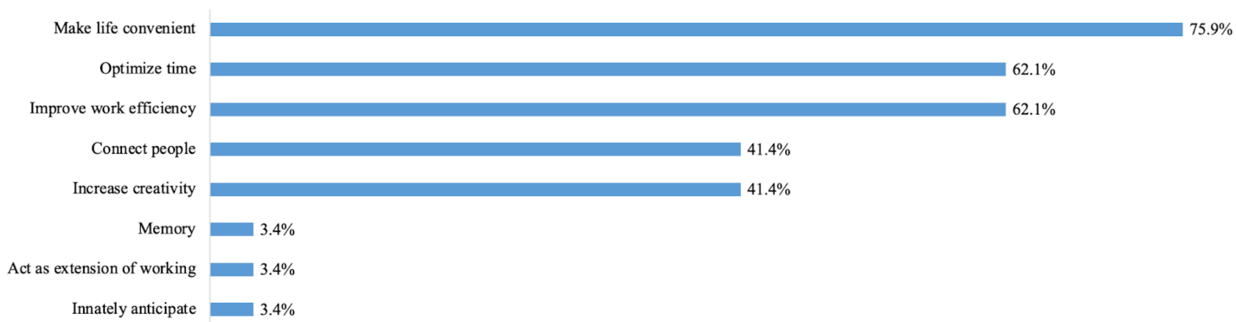
It made us conduct more comprehensive discussions with our experts on the concept of "convenience" during the interviews. Craig Mackiewicz, Founder and Principal Designer at Craig Mackiewicz Design, shared with us that in his understanding, most IoT products are designed to focus on people's convenience and benefit people without putting their own security at risk. One expert (participant 3), a senior industrial design manager at the leading global consumer robot company, said "I want every smart IoT device in my home to be seamlessly connected and to have the conversation so that I don't even need to bring my phone back and use it at home."

For them, convenience means spending less time in finishing tasks, gaining more benefits from the smart IoT system, optimizing people's work efficiency, and improving people's quality of life through using the smart IoT wearable devices, which perfectly echoed what Michael Abcunas, Director of Product Management at STANLEY, discussed with us in the interview "When I choose IoT products, I consider three aspects: 1. Efficiency—It can make my life convenient; 2. The pace of my life—It can help me control my life pace; 3. Cost—This is the least critical one since every product has its price."

Some experts had the opposite views about IoT products. "Most IoT products don't improve the quality of life for people, instead, it increases the outcome of life to make people work more. That's why I feel bored with it. IoT product design/industry is still in an infant stage. Most are still function-driven features by work efficiency improvement." said by Tobias Toft, Creative Director at Google.

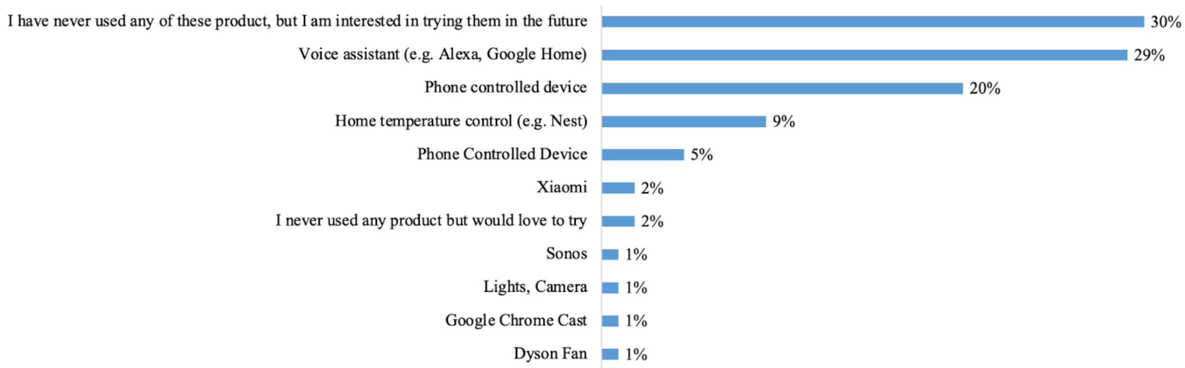
Julian Bleecker, Director at Near Future Lab, demonstrated to us one example of how IoT devices could increase people's creativity. He thought that the computer mouse was a great example to increase people's creativities, because it did help people "communicate" with the computer easily and intuitively. The computer mouse was like a creative instrument. Amelia Juhl, Design Director at IDEO, gave us another example "IoT device e.g., Apple watch can increase my creativity, because it can help me manage my stress and energy well to allow me to have space to have creative."

Figure 5.11. How you wish IoT wearable devices to help you.



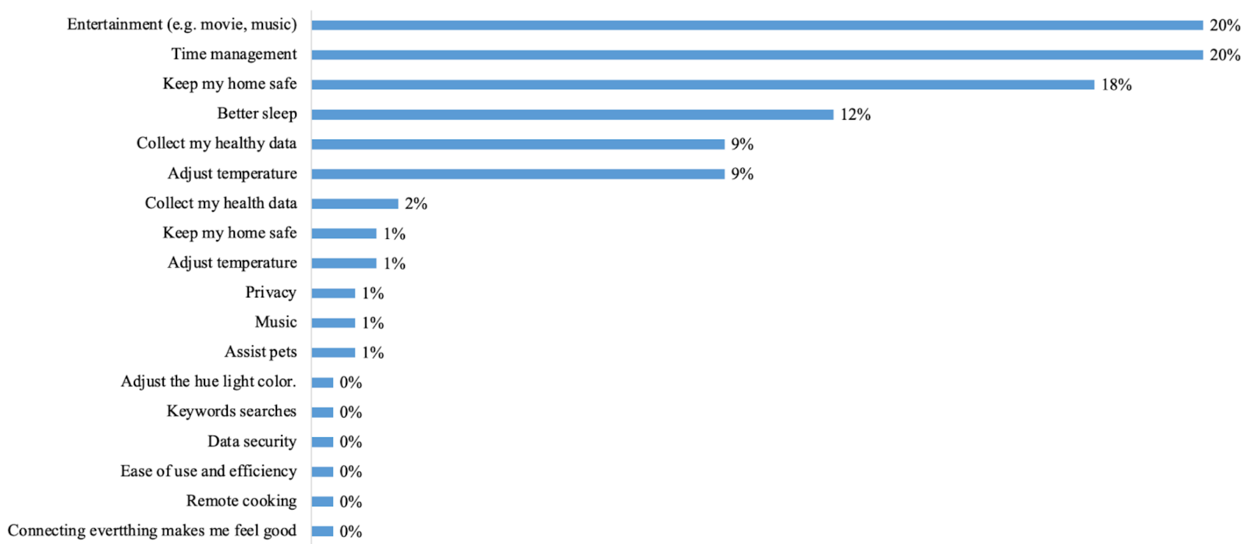
In Figure 5.12., the result shows that 29% had used voice assistants e.g., Alexa or Google Home, and 20% had used phone-controlled devices. Besides, 30% had never used any of these listed products on the options, but they were interested in trying them in the future. We assumed another reason was there were lots of IoT products on the market and we couldn't list them all in the pre-interview survey.

Figure 5.12. Have you ever used listed IoT products?



In Figure 5.13., 20% of interviewees selected entertainment; 20% chose time management; 18% thought to keep their home safe was critical; 12% wanted to have higher sleep quality; 9% collected their healthy data; 9% adjusted temperature. The result indicated people wanted to have an IoT wearable device to make their life convenient, monitor health conditions, and keep them safe.

Figure 5.13. What are the functions you think are important to you in terms of selecting IoT wearable devices? (choice 3 most applicable)



In the last question of our pre-interview survey, we wanted to get some ideas from experts to discuss the topic of this master thesis project—indoor footwear design for older adults. The intention was not to get design solutions from the experts. Instead, we wanted to learn where these ideas came from e.g., personal experience, pain points, expectations, and thoughts about the purpose.

The interviewees were asked to imagine if they were going to have a pair of smart footwear, without considering technological feasibility, economic issues, manufacturing cost, or other practical situations. How would they want their dream footwear under these ideal conditions? Figure 5.14. shows the functions of the smart footwear they wanted to have.

"If smart slippers can autonomously track people's movement, blood pressure, circulation, and other health conditions, it could be some great health-related features to add on." said one expert (participant 16), Founder and Principal at a product design, UX / UI design and mechanical engineering firm. Pedro Ferreira, Co-Founder of SiteLess House of Creatives and Adjunct Professor at Sungkyunkwan University, said that the healthcare-related IoT smart products, not limited to smart slippers, could help him prepare to have a better lifestyle. He analyzed himself when he made purchasing decisions regarding IoT devices with 80% considering the health-related issues and 20% considering his own interest.

Significantly, 65.5% wanted to have the function of detecting health conditions; 37.9% the feature of making people relax; 34.5% helping people exercise, and 20.7% tracking users' in-home trajectory. In general, health detecting, relaxation, and exercising were the top three dream functions that interviewees would love to have if they designed a pair of smart footwear.

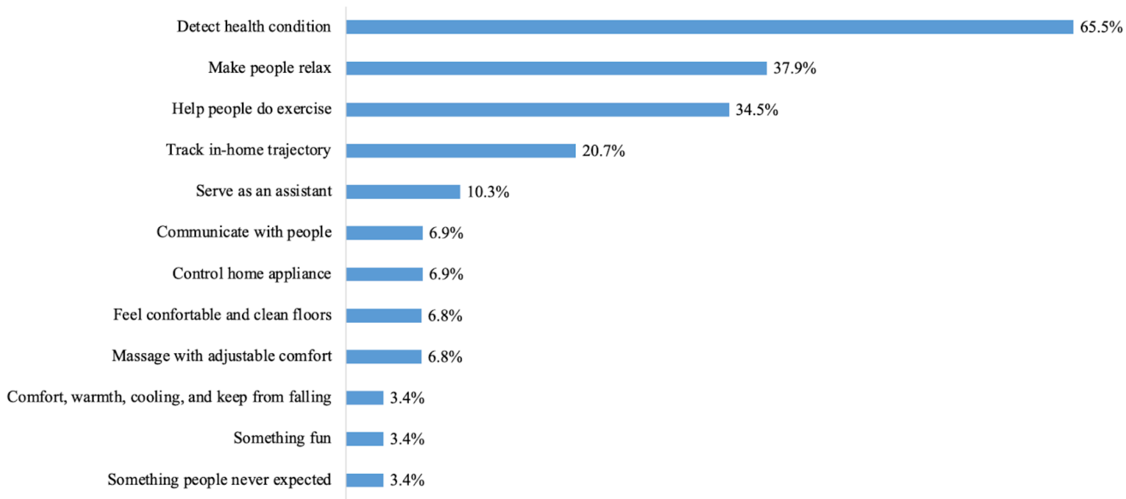
In addition to discussing the features of a product, Paul Hatch, Partner at TEAMS, mentioned the importance of considering product design in the shoes of user experience, "A successful IoT product won't market it as an IoT product, since people won't purchase an extra coffee machine with sensors. Instead, designers need to reinvent the overall user experience when people use a coffee machine."

In another expert interview, Taylor Greenberg Goldy, Behavioral Designer at McKinsey & Company, viewed the concept of smart footwear as a research tool. She said "The concept of smart slippers can be used as a UX research tool to track people's behavior. It can be useful for the medical staff, doctors to monitor patient's health conditions." Besides, she felt one great product feature that can be added to the smart slippers is to remind people to move or walk after sitting in place for a while, especially now people spend the majority of their time working from home. She also suggested that the smart slippers can be added to the pressure sensor on the sole to help adjust peoples' walking posture.

Sandeep Pahuja, Director at IDEO and Lecturer at Berkeley-Haas, provided us with a cultural perspective to review this question. "When it comes to the concept of smart slippers, there is a cultural difference that most westerners put on their sneakers all day. People will put on different shoes in different scenarios. For example, when people do in-home training, they might put on work-out shoes and they might not wear slippers at home." He also brainstormed that the format of the smart slippers could be designed in a modular clip so that it was attached to different in-home shoes.

For further studies, we can compare the result of the footwear functions when the participants change from the roles of experts to care recipients e.g., older adults or caregivers e.g., older adults' family members or the medical teams.

Figure 5.14. If you have a pair of smart slippers, what kind of functions do you want to have?

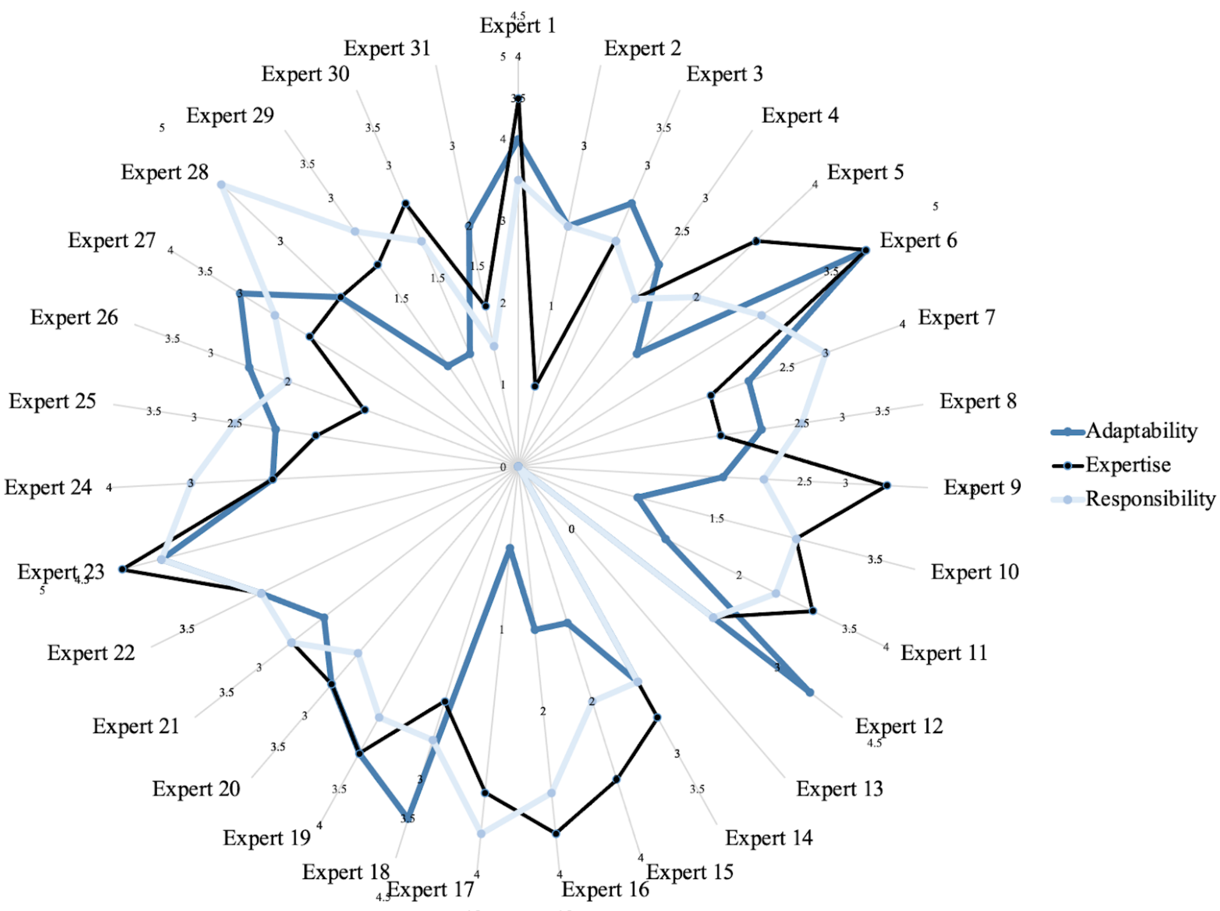


5.2.4. ARE Evaluation Result

After each expert interview, the internal interview team had to score the interviews from 1 to 5, based on the ARE evaluation framework. The ARE framework assisted us in 1) analyzing our interview discussion in terms of experts' knowledge, perception, and understanding of IoT wearable devices and industries, and 2) refining the framework for further studies. Figure 5.15. shows the ARE evaluation result of 31 expert interviews.

There was no score for Expert 13, because he didn't participate in virtual interviews. Instead, we used emails to get his response to the same expert interview discussion guide paired with pre-interview survey questions. The full scores of ARE evaluation result were displayed in Table F.1. of Appendix F—ARE Evaluation Result.

Figure 5.15. ARE evaluation result of 31 expert interviews (same as Figure F.1.)



5.3. Summary of Expert Interviews

Conducting 31 expert interviews was helpful in this study. We gained insight into industry knowledge and understanding of smart IoT wearable device design in a relatively short time grounded in experts' work experiences. Since all 31 expert interviews were conducted online, learnings and reflections not only included an exploration of content (e.g., smart IoT wearable product design), but also examined the possibility of refining digital interviewing tools, for which further research is needed.

Therefore, our key learnings in this chapter focus on two parts: 1) how to refine and curate better expert interviews through technologies and structural research methodologies and 2) how to design human-centered IoT wearable devices not only for older adults, but also for the general public.

5.3.1. Improved Research Methodologies through Technologies

1) Set expert interviewee recruiting criteria.

Besides using the interviewees' background information—gender, expertise, job titles, and education—as fundamental filters, establishing the right set of recruiting criteria was integral to helping us identify the "right" experts for this study to ensure we could generate high quality research results and save time on analysis.

We applied the ARE framework to analyze the expert interview result: Adaptability—to understand the comfort level of the interviewee when facing IoT products and their challenges; Expertise—to understand how knowledgeable the interviewee is about the IoT industry; and Responsibility—to understand the perception of the interviewee about the ethics of IoT and data-privacy-related issues. But we did not have specific criteria that focused on our research topic.

In this study, we started by recruiting experts from our personal connections through email, social media, and telephone. For future studies, we should establish a series of structural criteria to help us recruit suitable candidates. For example, we could consider not only experts' gender identities, industry and work experience, length of time in the field, their familiarity with the research topic, but also their ability to articulate their thoughts, and the extent of the information they can share because of confidentiality concerns.

2) Design engaging sections in interviews.

Alough the expert interviews were conducted entirely virtually, there were many similarities in terms of participants' needs during the online interview. The majority of interviewees were recruited through personal connections, so we had met before, or at least they had known us. Under normal circumstances, how might we improve the virtual interview experience for both interviewers and interviewees to generate high-quality results?

We integrated three engaging sections in each interview, creating a 3-minute pre-interview survey serving as an ice-breaker, designing a few Zoom polls during the interview to increase the level of interaction, and setting a rigid biology break during the transition between different topics within the 45-minute interview time slot. These sections were very helpful both for interviewees and facilitators because they quickly established relevant, data-driven talking points, eased moments of awkward silence in the interview, and built trust, all while making the conversation more constructive.

3) Consider other formats to conduct remote interviews.

We also learned that there were many other approaches to conducting virtual interviews. Besides videoconferencing (e.g., Zoom, Google Meet), we considered that traditional communication methods like phone calls might also be effective and direct. Further research can explore the extent to which videoconferencing contains a visual distraction. Through audio communication, interviewees and facilitators might pay more attention to the content of their conversations.

5.3.2. Product Design Consideration for IoT Wearable Devices

1) The shift from product-centered to people-centered design

Recordings and notes were taken of the 31 expert interviews to ensure we focused on not only what participants had to say, but also the subtleties around users' pain points, unmet needs, and expectations. We also compared the expert interview notes with pre-interview survey results to discuss the significant mismatch and how we interpreted some of these interesting findings.

For example, from the pre-interview survey, 75.9% of experts said they wished IoT wearable devices could make their life convenient (Figure 5.11.). But what was less explicit was why convenience mattered to them or to their target users. "Most current IoT smart products are designed for ease of use, and convenience. Objects make people's lives easier. But what are people's real needs?" said Jerome Goh, Design Lead at IDEO, Adjunct Assistant Professor at Newschool. It also resonated with the perspectives of Angie Kim, Founder at AYK LLC, that the IoT device needs to be intuitive to use and know the user's behaviors and habits.

Future IoT wearable device and service design should shift from product-centered to people-centered design, which echoed what Tobias Toft, Creative Director at Google, shared with us, "Most IoT products don't improve the quality of life for people, instead, it increases the outcome of life to make people work more. That's why I feel bored with it. IoT product design/industry is still in an infant stage. Most are still function-driven features by work efficiency improvement."

Paul Hatch, Partner at TEAMS, even pushed people-centered design further to the IoT experience. He reminded us that as designers, we needed to consider three aspects: awareness, improvement, and mindfulness while designing IoT experiences for users.

2) Emotional Intelligence (EI) is the fuel of Artificial Intelligence (AI)

Paul Hatch, Partner at TEAMS, talked about the fact that when consumers purchase or use a product, their emotional reaction comes first and rational information second. It led us to think of Emotional Intelligence (EI) mentioned by Tobias Toft, Creative Director at Google. He said, "The process of designing IoT products is not that different from other traditional product design development processes. What matters is the human value and human needs."

In short, Toft surmised that most IoT product designs and services were actually driven by people's laziness. For example, people do not want to push the light switch even though it is a simple action. Why did they need to push the button if they can control everything with one hand or through their voice?

Laziness-driven design can be redefined as we study people's behavior. Further design research topics can integrate EI and users' behavior to ask: How can we create more joy at home? How can IoT smart devices create more poetic moments at home? How do we design an IoT product with emotional intelligence? How do we establish trust between IoT devices and users?

3) Create IoT ecosystems to build users' platform awareness

"I will consider the consequence every time I need to create a new IoT device. We need to think about the issue in the context of the global environment since we only have one earth," said Lionel Wodecki, Design Architect at GE Healthcare. When people purchase IoT products, their decision-making might be influenced by the IoT platform (e.g., different brands with various operating systems). As designers of IoT products or systems, he suggested we designers need to ask ourselves these challenging questions: "Why do we need to create a new IoT product? What's the purpose of creating a new one? We need to take sustainability into consideration every time designers have a new idea. We need to develop holistic thinking to view the ideas from multiple angles."

One expert (participant 16), Founder and Principal at a product design, UX / UI design and mechanical engineering firm, shared his views from users' angles, "What's missing for IoT devices is that there is no centralized platform. I want to install a Nest thermostat, but my existing heating system is a European spec, which conflicted with Nest. As a consumer purchasing an IoT product, it is less about the product, but more about the issue of the cross-platform." He thought there were lots of redundant IoT products since IoT products relied on their individual ecosystem. Consumers will consider the platform and system first, but not the actual product. He said it's a bit difficult for him to change the iPhone he's been using if he is going to purchase a new IoT product.

Designing IoT products need to consider the interaction with people, products, and experience. As product architects, we need to view the product design in a holistic way by considering the system and platforms it is a part of.

4) Design with data enabling social responsibilities

Technologies have gradually transformed peoples' lives, work, and the approaches we need to apply to solve social-technological challenges. Everything in life is interconnected, due to technology and the Internet. "The beauty of IoT is that it is actually embedded into your workflow and makes your life seamlessly connected. The only thing you need to do is see your screen," said Taylor Greenberg Goldy, Behavioral Designer at McKinsey & Company.

Data has become a currency of technology shaping our communication and communities. "Meanwhile, there is a broader ethical issue that we need to be aware of," said one expert (participant 28), Director of Global Design at an American multinational technology corporation. He viewed data as a straightforward material that could be a useful tool to inform designers and their design processes. But how were we to assure that the data collected was unbiased? One expert (participant 25), a Senior UX Researcher at a no-code customizable field service software company, hypothesized that most people don't have enough knowledge on the topic of data ethics. She held positive views on design with data and thought the design process by integrating data of users or herself was insightful because it made her decision-making in complicated scenarios much easier and more actionable.

In general, the future of design is about maintaining balance in every aspect, especially the balance between data and human connection, which has become increasingly important and sensitive, and everyone should be mindful of and take care of the social responsibilities generated thereby.

Figure 5.16. Conduct an online expert interview with one expert (participant 15), former design lead at a design and consulting firm. (photo credit: Sheng-Hung Lee)

Chapter 6. User Survey

Gordon Salchow talked about how designing requires insight, objectivity, and clarity, but the designer's personal voice also humanizes the result, making it more approachable [140]. Besides receiving perspectives from both designers and experts, we also listened to what our target users wanted to share with us about their experience, pain points, and unmet needs of indoor footwear design in Chapter 6.

6.1. User Survey Research Questions and Objectives

For the user survey, we studied people's wearing and purchasing behavior of indoor footwear across different ages, and their feedback on the ten footwear concepts in the early stage of product design and development. To effectively leverage the survey result, we reframed the following four research questions with an emphasis on older adults: 1) What is the current user experience of older adults when they purchase and wear footwear? 2) What is older adults' knowledge about choosing suitable footwear? 3) How do technology and service impact the approach of footwear design for older adults?

Finally, because this research was conducted during the COVID-19 pandemic, our final question is 4) What insights and implications are there around the design of indoor footwear for older adults and how do we gather insights from older adults by using remote technologies?

6.2. User Survey Result

We shared not only our survey results, but also insights from our interpretation of information. Our interpretation was based on the previous literature reviews, user interviews, expert interviews, and our understanding of data paired with survey results.

We followed the sequence of the survey questions to present our analysis process, since this also helped us be more emphatic in the shoes of participants by following the same flow while they filled out the survey.

6.2.1. Demography

We used Qualtrics to conduct the two-week online user survey to gather a total of 495 users' feedback, where the majority of survey participants were from Boston, the United States and Taiwan. The two-week recruiting process of survey participants was built upon the MIT AgeLab database—85^{+} Lifestyle Leaders [126] and also from the author's personal connections.

After filtering out incomplete survey responses, we identified 115 valid responses used for analysis and categorized them into Group A (aged 18~30), Group B (aged 31~60), and Group C (aged 61~100).

Table 6.1. The demography of survey participants

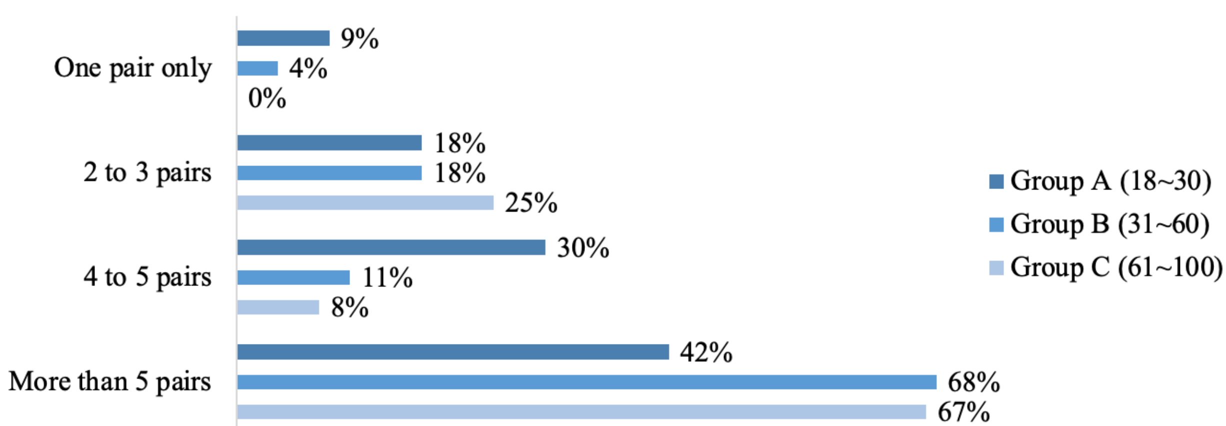
	Group A	Group B	Group C
Number of participants	n = 43	n = 38	n = 34
Percentage	37.4%	33.0%	29.6%
Age range	18~30 years old	31~60 years old	61~100 years old
Gender	Male 33% Female 64%	Male 50% Female 50%	Male 50% Female 50%

6.2.2. User's Wearing Behavior

Number of pairs of Footwear: In this survey question, we asked participants how many pairs of shoes they own, not including those of their spouse, children, or other family members. According to the results (Figure 6.1.), most participants have more than 5 pairs of shoes at home and the percentages are close to or exceed 50%: Group A (42%), Group B (68%) and Group C (67%). 30% of Group A, the younger generation, have 4 to 5 pairs of shoes at home, which is relatively higher than Group B (11%) and Group C (8%).

The number of shoes that survey participants have across three different age ranges can reflect many contextual factors: purchasing power, lifestyle, living conditions, and health conditions. For older adults, the fact that 67% of them have more than 5 pairs indicates a few scenarios: 1) they can't find a suitable pair of shoes for themselves, so they keep purchasing more different brands of shoes; 2) they need different types of shoes for multiple situations, indoors or outdoors e.g., shoes for sports, shoes for walking, and shoes for formal events; 3) they're already financially independent, so they don't care about the number of shoes they want to purchase.

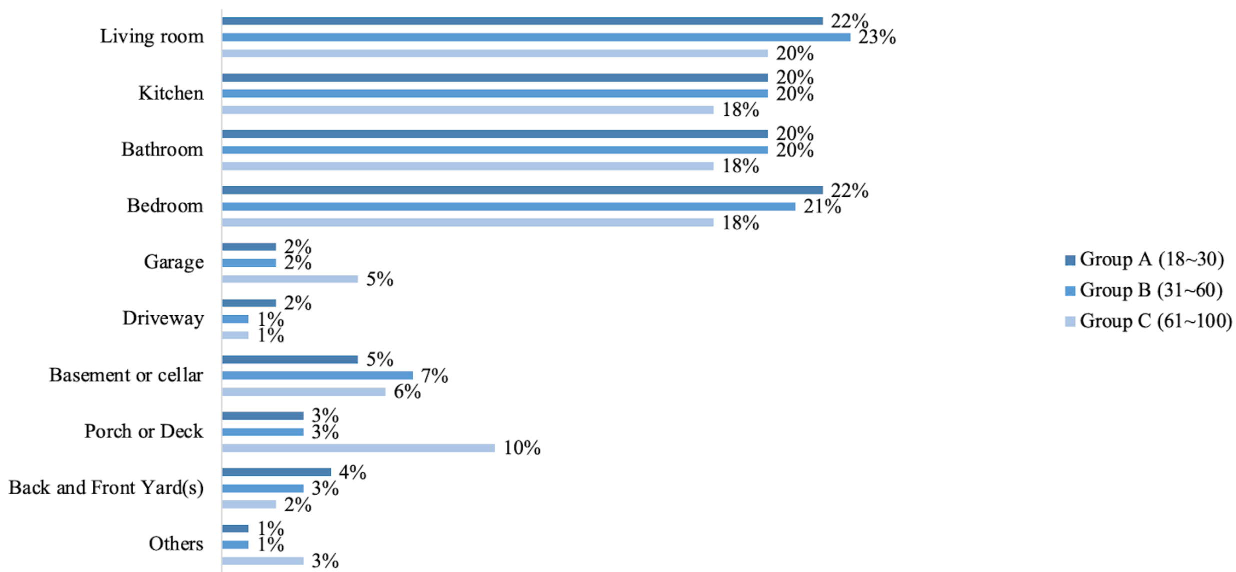
Figure 6.1. How many pairs of shoes (e.g., sneakers, loafers, sandals, boots) do you currently have in total in your home, including the shoes you own and use?
(Appendix H: survey question 3.2.)



Perception of Indoor Space: We want to have a better understanding of the perceptions of "indoor space" from our survey participants. The result (Figure 6.2.) showed that approximately 18% to 23% of all three groups recognized that indoor space included: living room, kitchen, bathroom, and bedroom. When we discussed the area of the porch or deck, 10% of Group C thought it was an indoor space, which was relatively higher than Group A (3%) and Group B (3%).

This question was critical to us since we focused on designing better indoor footwear for older adults. The concept of "indoor space" differed from person to person, but at least from the survey result, we can observe there was some significant overlap in terms of indoor space. It influenced the footwear design features that we want to integrate.

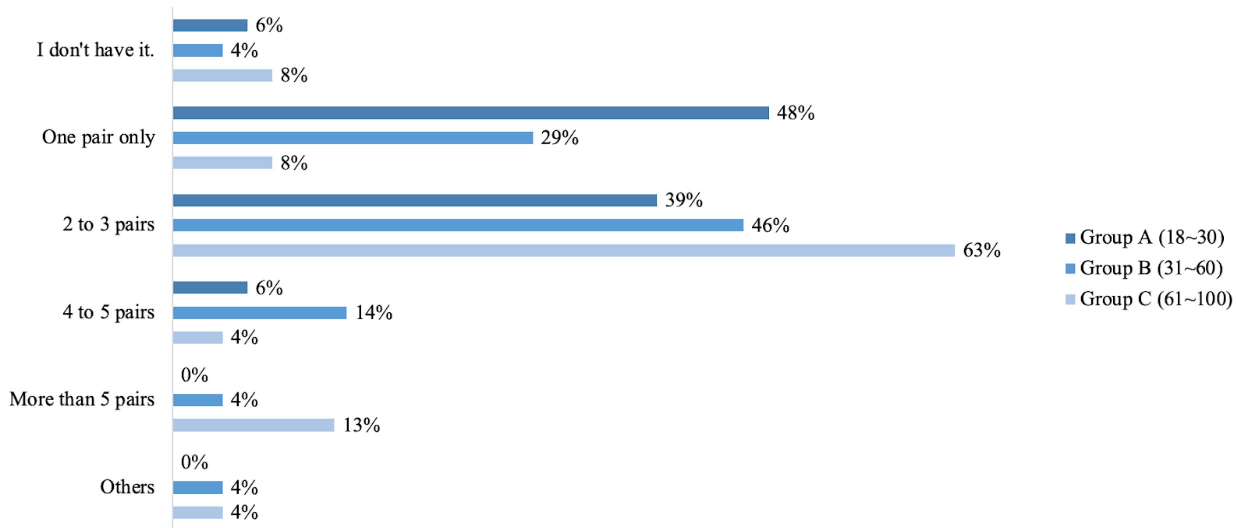
Figure 6.2. Which of the following spaces in your home do you consider to be an "indoor" space? Select all that apply. (Appendix H: survey question 3.3.)



Number of Indoor Footwear: In this survey question, "indoor footwear" refers to footwear that is meant to be primarily worn indoors instead of outdoors. 63% of Group C had 2 to 3 pairs of indoor footwear, which was relatively higher than Group A (39%) and Group B (46%). 8% of Group C didn't have any pairs of indoor footwear (Figure 6.3.).

For the younger generation, 48% of Group A had only one pair. We hypothesized that for Group A, their time spent at home was short, especially compared with Group C. Therefore, it didn't create a strong user need for Group A to purchase more than one pair of indoor footwear, whereas older adults of Group C stayed relatively longer indoors, so they might have more than one option of indoor footwear.

Figure 6.3. How many pairs of "indoor" footwear do you have?
(Appendix H: survey question 3.4.)



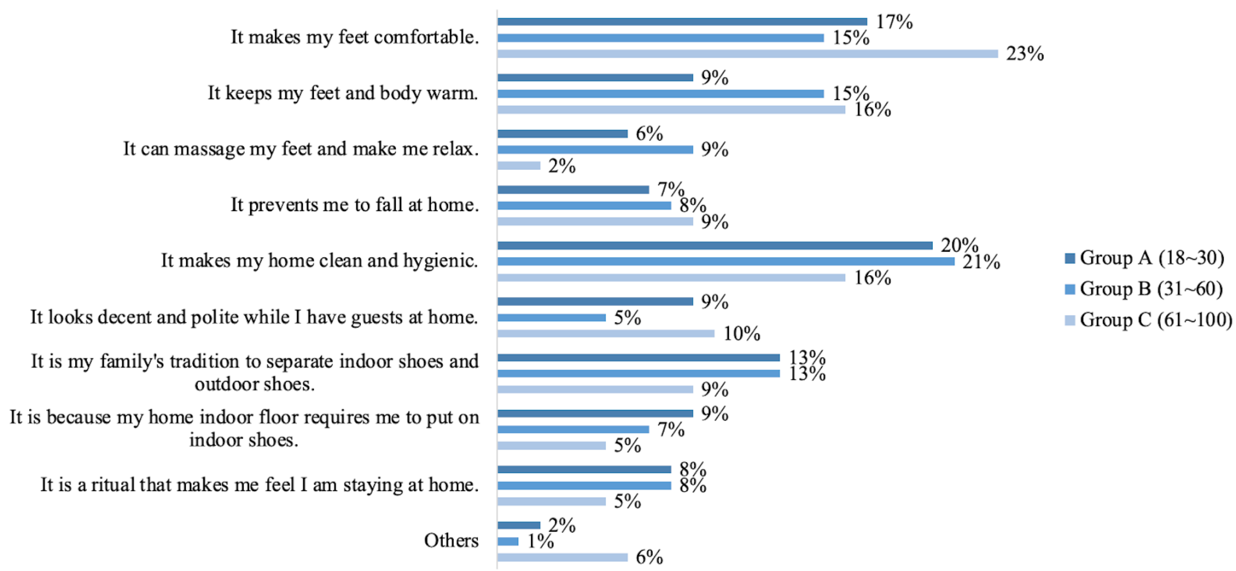
<u>*Motivation of Wearing Indoor Footwear:*</u> Besides knowing the number of indoor footwear that survey participants had, we explored further to understand their motivation of wearing indoor footwear at home (Figure 6.4.).

This question explored participants' motivation to wear indoor footwear from functional aspects (e.g., prevent falling down, keep feet and body warm, massage feet to relax, look decent and polite) as well as emotional (e.g., feel comfortable), and cultural (e.g., daily-life ritual, family's tradition) angles.

The results showed 23% of Group C wanted their indoor footwear to make their feet comfortable, which was similar to the other two groups. But Group A (20%) and Group B (21%) showed stronger motivation to use indoor footwear to keep their home clean and hygienic.

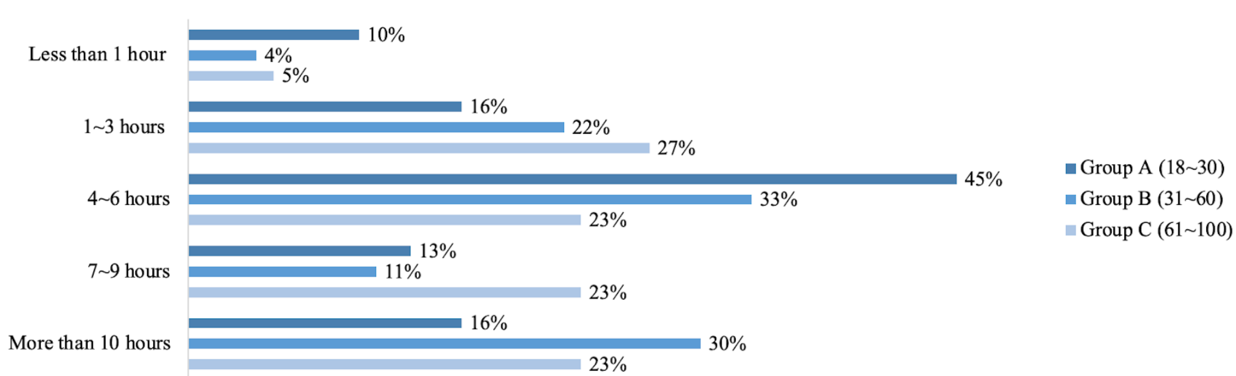
Interestingly, only 9% of Group C thought about preventing them from falling at home and 2% needed the function of foot massage to relax. Safety was the main concern that we thought older adults would have, but the results showed that comfort was much more critical.

Figure 6.4. Why do you wear indoor footwear at home? Select all that apply. (Appendix H: survey question 3.5.)



Time of Wearing Indoor Footwear: The top 1 of each group was: 45% of Group A tended to wear their indoor footwear for 4 to 6 hours. 33% of Group B had a similar result as Group A. Only 1% of Group C said they wore indoor footwear for less than 1 hour at home, whereas 23% revealed 7 to 9 hours and 23% even said more than 10 hours. Not surprisingly, older adults tended to wear their indoor footwear longer, since we assumed that they spent more time indoors (Figure 6.5.).

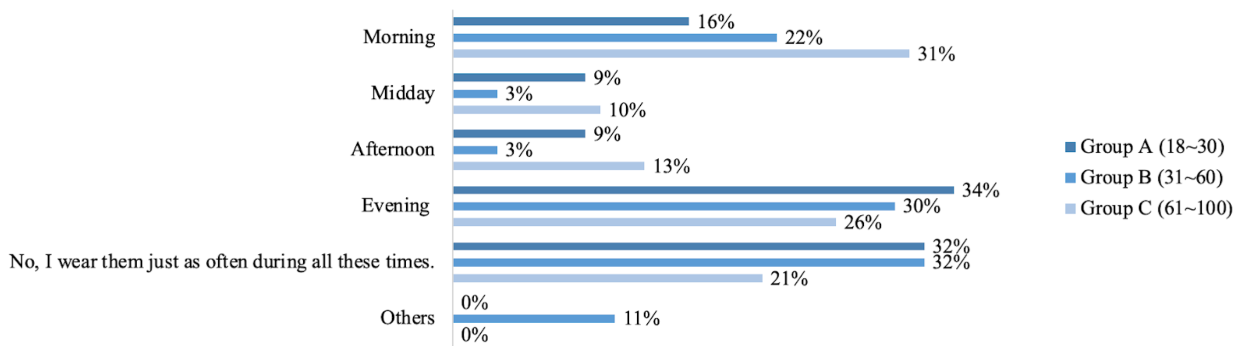
Figure 6.5. On a typical day, how many hours do you tend to wear your indoor footwear when you are at home? (Appendix H: survey question 3.6.)



Moments of Wearing Indoor Footwear: The question can help us understand their behavior on a typical day. In Figure 6.6., Group A and B indicated that they probably went to school or office during the day, since the sum of the percentage of their evening options added up to 64%. If we looked at Group C, the option of the morning (31%) and the evening (26%) took almost half of the percentage. We can assume that older adults were more active in the morning and evening while spending most of their time at home.

From the survey result, even though the options of midday and afternoon were relatively low in percentage across three groups, we could view this as an opportunity to brainstorm what design features or service components can indoor footwear products be integrated with.

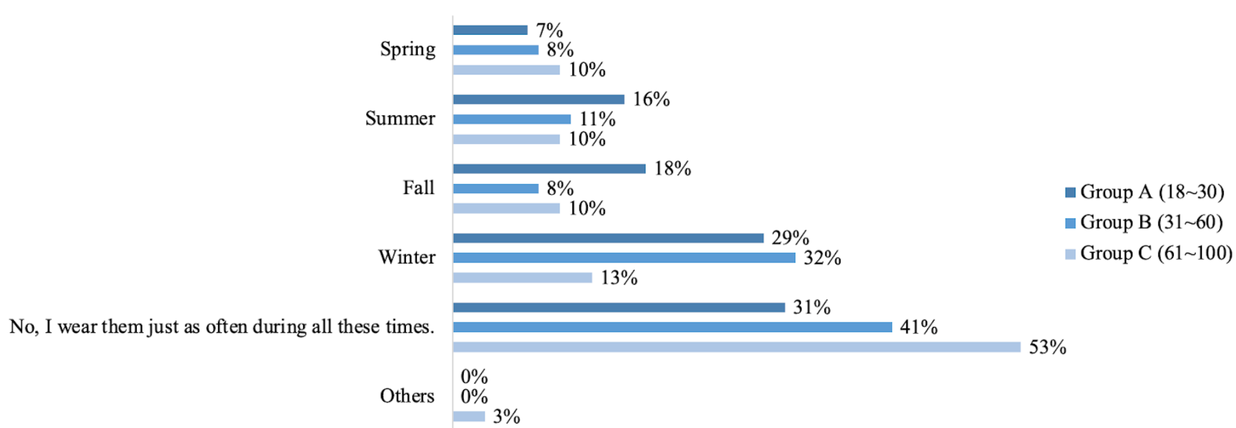
Figure 6.6. What time of day do you wear indoor footwear most often? Select all that apply. (Appendix H: survey question 3.7.)



<u>*Seasons of Wearing Indoor Footwear:*</u> Similar to the question above, we wanted to know more about their wearing behavior. In this question (Figure 6.7.). We asked them in which season they wore indoor footwear most often for our consideration in the future, while we designed the indoor footwear: what kind of materials are breathable to fit specific types of seasons (e.g., humid weather, dry conditions, or low temperature).

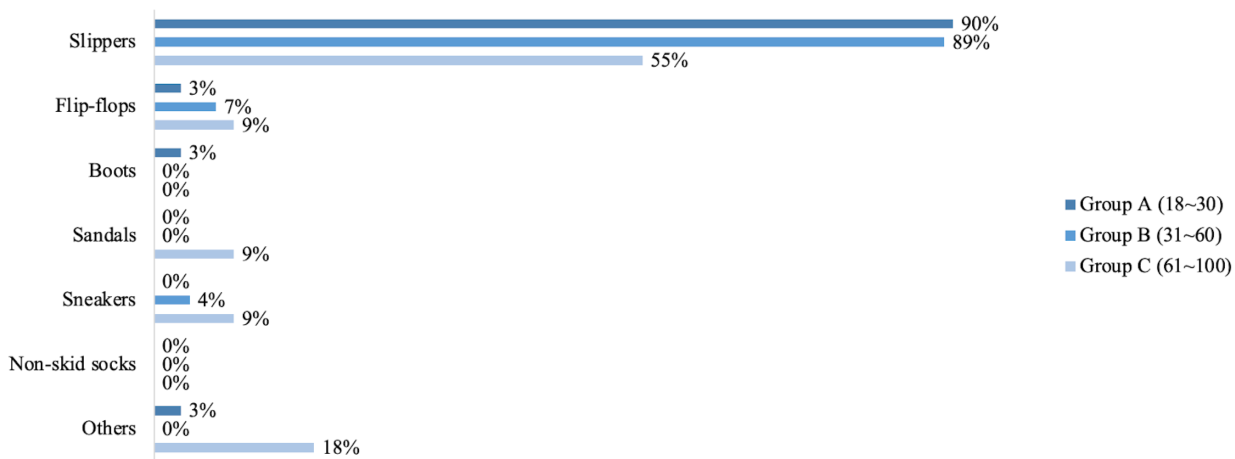
29% of Group A and 32 % of Group B chose winter, which might explain why the survey participants wanted to have the product feature of keeping their feet and body warm. We also observed that, for 53% of Group C, wearing indoor footwear was independent of the season.

Figure 6.7. What season do you wear your indoor footwear most often? Select all that apply. (Appendix H: survey question 3.8.)



Types of Indoor Footwear: The survey result significantly aligned across three groups that the participants replied that slippers were the kind of indoor footwear they wore most often indoors (Figure 6.8.). No one selected non-skid socks. Group C, older adults, selected flip-flops (9%), sandals (9%), sneakers (9%), but 18% had various situations where they needed different types of indoor footwear.

Figure 6.8. What kind of indoor footwear do you wear most often?
(Appendix H: survey question 3.9.)



Indoor Footwear Storage: We were curious to know where the survey participants stored their indoor footwear. 68% of Group C had a designated space to store indoor footwear such as a corner, closet, front door, and shoebox (Table 6.2.)., whereas for the younger generation, close to half of Group A (42%) didn't have designated space for their footwear. This might be related to participants from different age ranges with different lifestyles.

Figure 6.9. Do you store your indoor footwear anywhere in particular in your home when you take them off? (Appendix H: survey question 3.10)

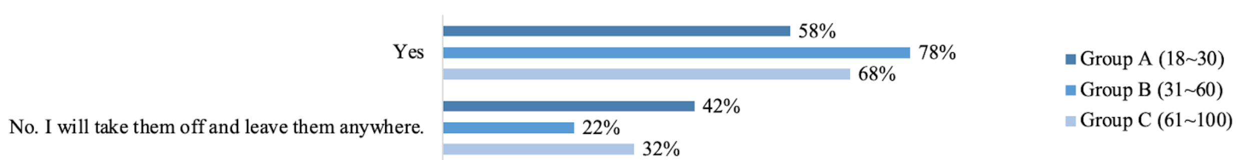


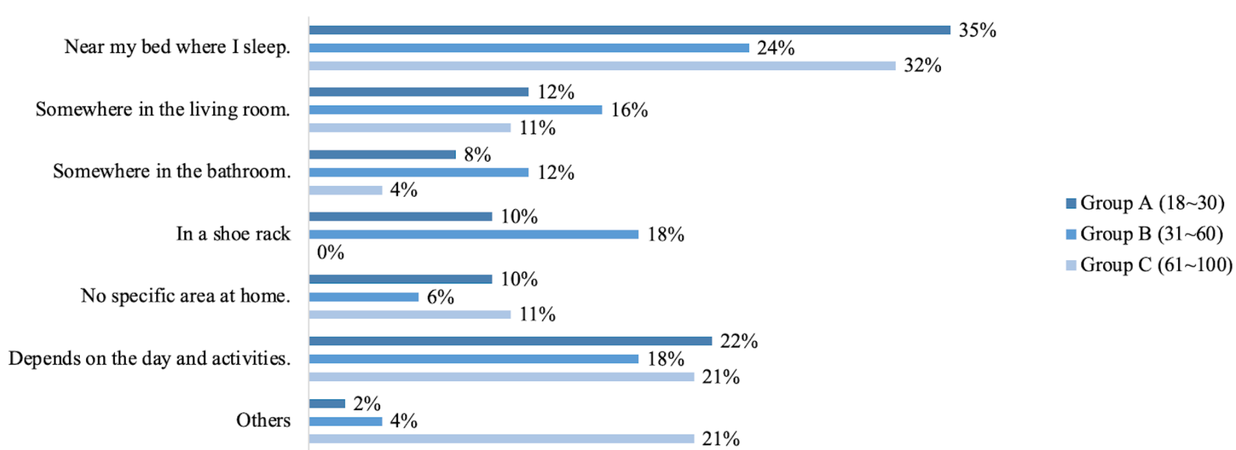
Table 6.2. Where do you typically store your footwear at home?
(n means number of response shown, Appendix H: survey question 3.11.)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Response	n	Response	n	Response	n
• shoe cabinet	7	• shoe cabinet	8	• close	2
• floor	1	• shoe box	2	• a corner	1
• porch	1	• shoe rack	2	• front door	1
• carpet	1	• reception	1	• by the bed	1
• corridor	1	• anywhere	1	• shoe cabinet	1
• at home	1	• on the stair	1	• in my bedroom	1
• shoe ark	1	• next to the stairs	1	• a shelf or corner	1
• shoebox	1	• closest by the front door	1	• the shoe storage	1
• living room	1	• on the floor or in the shoe cabinet near the door	1	• the floor of the door	1
• household shoe ark	1	• shoe cabinet near the front door	1	• shoe tree in a closet	1
• front door entrance	1	• with other shoes on the shoe rack near the entrance	1	• under dresser drawers	1
				• in my walk-in clothes closet	1
				• front door or put on the shoe box	1
				• near the entrance to my apartment	1

Not surprisingly, most survey participants (close or exceed 30%) put their indoor footwear near their bed, since it was intuitive and easy for users (Figure 6.10.). 18% to 22% of the survey participants across Group A, B, and C were dependent on the day and activities to decide where they put their indoor footwear.

Compared with Group A (2%) and B (4%) of option "Others", 21% of Group C significantly had various needs to store their indoor footwear connected to their mobility, health conditions, and living environment. Indoor footwear design should consider users in context and how they store their shoes at home.

Figure 6.10. Think about the pair of indoor footwear you wear most often in a day, where do you most often put or store that footwear if you want to take them off for a while? Select all that apply. (Appendix H: survey question 3.12.)



Experiences of Putting On and Taking Off Indoor Footwear: We analyzed Figure 6.11. and 6.12. together, since both questions were discussing the experience of putting on and taking off their indoor footwear. Unsurprisingly, three groups were aligned with our expectation and the result that most survey participants didn't need to put on or take off their indoor footwear using their hands.

25% of Group C needed to use one hand to adjust the room/space of their toe box or heel to help them put on their indoor footwear. What impressed us was that 13% of Group C, older adults, needed assistance with both hands to put on and take off their indoor footwear. We assumed the two reasons: 1) older adults might need more strength to put on or take off their indoor footwear; 2) there was no great indoor footwear design for older adults ergonomically on the market, so they might need extra effort to put on or take off their indoor footwear.

Figure 6.11. Please select the following that most accurately describes how you put on your indoor footwear. Select all that apply. (Appendix H: survey question 3.13.)

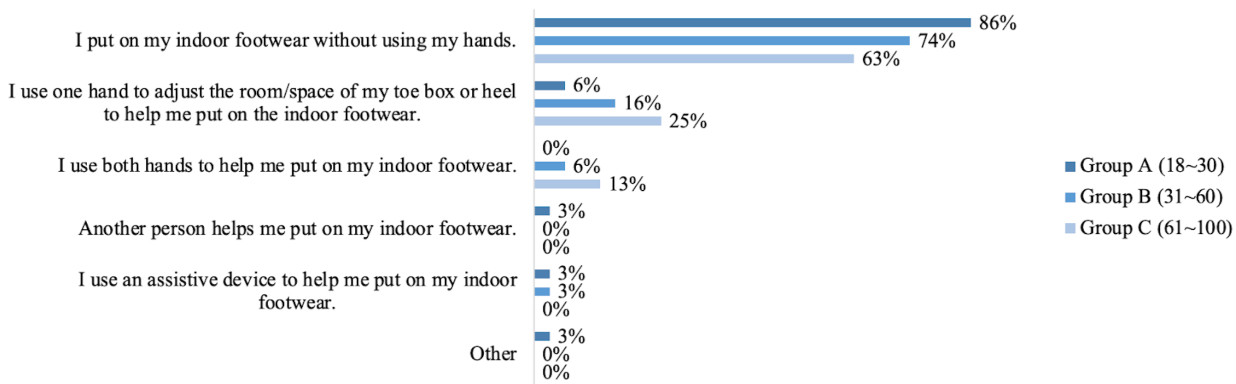
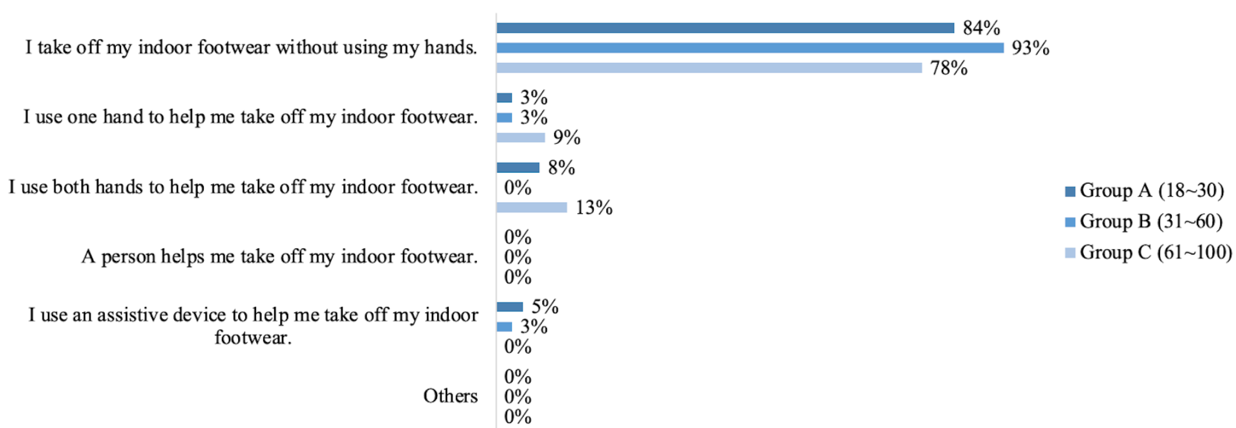


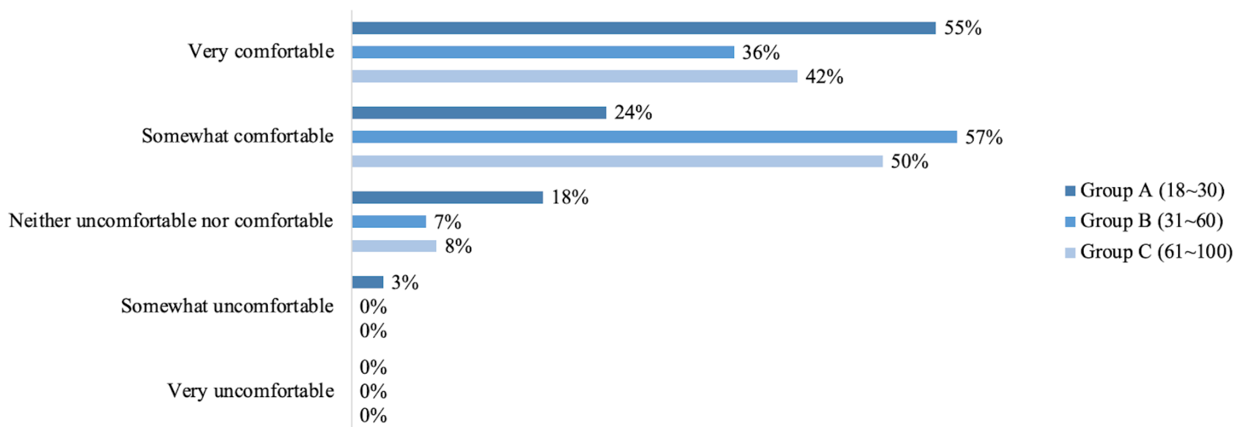
Figure 6.12. Please select the following that most accurately describes how you take off your indoor footwear. Select all that apply. (Appendix H: survey question 3.14.)



<u>*Comfort Level of Indoor Footwear:*</u> Figure 6.13. showed the top 1 choice across three groups: Over half of Group A felt their primary pair of indoor footwear fit their feet very comfortably (55%). 57% of Group B and 50% of Group C felt somewhat comfortable. There was some percentage of neutral answers "neither uncomfortable nor comfortable", but the majority of survey participants were positive in response to the questions.

However, we were curious about participants' perception of the term "comfortable", since no one selected the option "very uncomfortable". It was because this was too extreme to describe the current situation or that participants don't want to reflect the reality of their comfort level while wearing indoor footwear or that they don't know whether "comfort" is the right word.

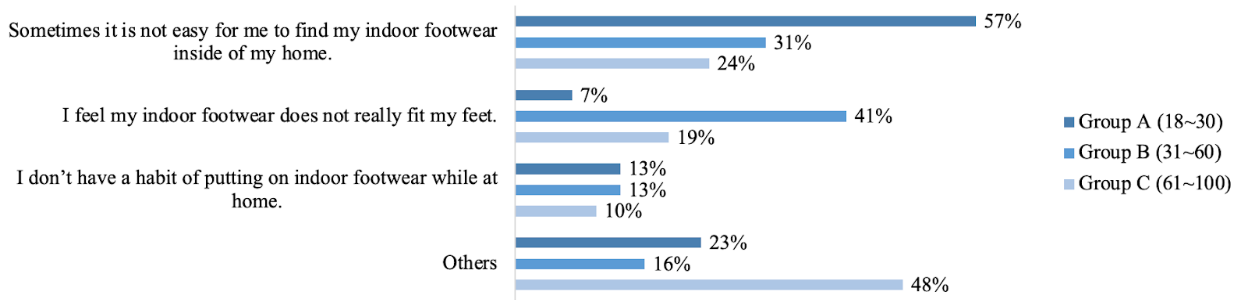
Figure 6.13. How comfortable are you with how well your primary pair of indoor footwear fits your feet? (Appendix H: survey question 3.15.)



In Figure 6.14., the top list among the three groups were: 57% of Group A said it was not easy for them to find their indoor footwear; 41% of Group B felt their indoor footwear didn't really fit their feet, and close to half of the percentage of Group C (48%) had shown various pain points.

For example, one survey participant said, "Healthcare information may be attractive to me if my indoor shoes can track my weight and other vital signs will be perfect." Another one shared, "A pair of indoor footwear appears when I need it, but it can disappear when I don't need it." Someone shared in the survey that "I would want more personalized indoor footwear service if I spent a lot on the shoes. I would prefer to purchase reasonably priced indoor footwear and the company can regularly replace it as it wears out or update the indoor footwear features."

Figure 6.14. What are some of the most frustrating things you experience in regards to your indoor footwear? Select all that apply. (Appendix H: survey question 3.16.)



Emotional Reaction of Indoor Footwear: Figure 6.15. and Figure 6.16. were the questions to probe participants' emotional reactions through ten various mood board images to understand their feeling and perception of their own indoor footwear experience (Table 6.3.). Appendix I had documented details of the intention of why and how we used each mood board image and captured keywords they used to describe the ten mood board images. It helped the research team to get the survey participants' insightful feedback.

Table 6.3. Mood board images overview (same as Table I.1. and sources from the Internet)


Image 1


Image 2


Image 3


Image 4


Image 5


Image 6

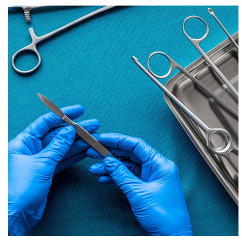


Image 7


Image 8

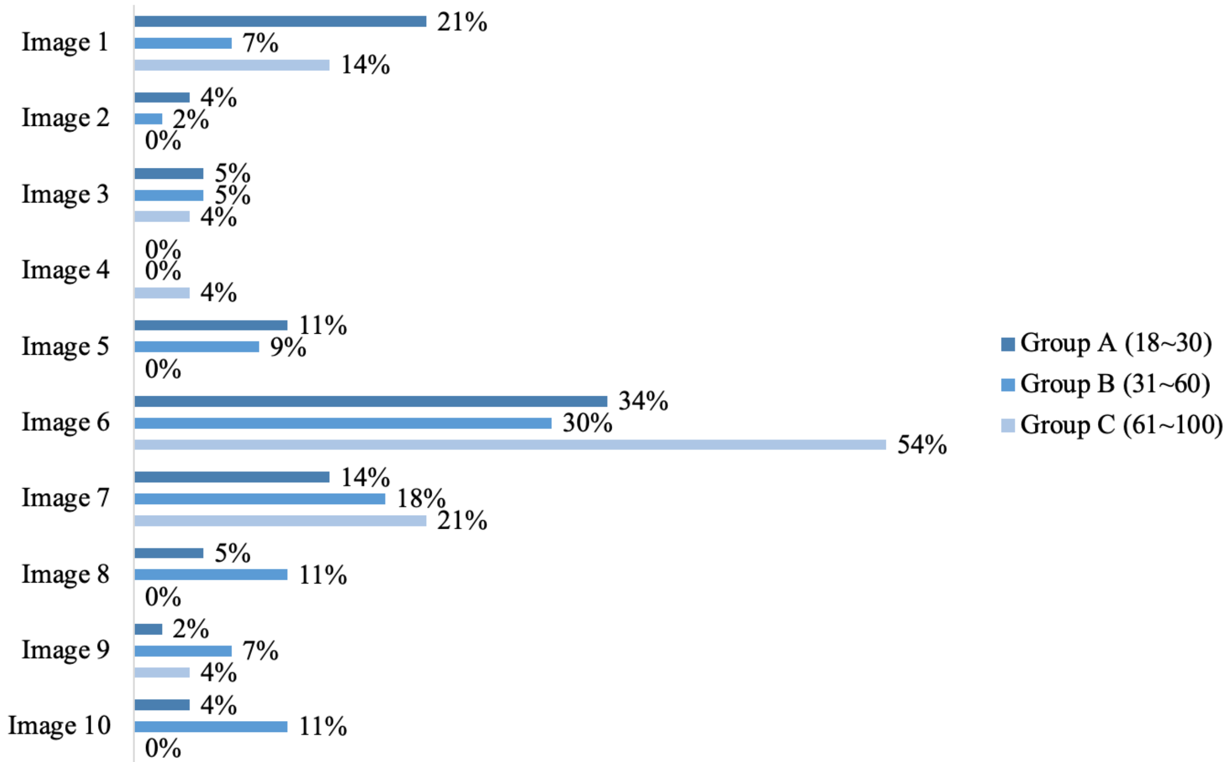

Image 9


Image 10

Current Feelings of Indoor Footwear: 54% of Group C stood out significantly, choosing image 6 to best describe their current feelings while they put on their most frequently worn pair of indoor footwear (Figure 6.15.). Our intention of using image 6 was to send a message of a surge of excitement, adventure, joy, and achievement while people wear shoes. Since surfing was an extreme sport, we wanted to translate the surfing experience into people's footwear wearing experience.

White and Mulley shared their research that older adults who were able to wear shoes regard this behavior as a symbol of continued independence [10]. Besides a symbol of continued independence, older adults, Group C, also crave for a sense of speed, adventure, coolness, and freedom in life.

Figure 6.15. Please select the images that best describe your current feelings when you put on your most frequently worn pair of indoor footwear? Select all that apply.
(Appendix H: survey question 3.17.)



<u>*Ideal Experience of Indoor Footwear:*</u> The survey result showed that images 2, 4, 9, and 10 had very low percentages across three groups, which were not suitable visuals to describe the survey participants' ideal indoor footwear experience (Figure 6.16.). In addition to knowing what the survey participants liked, we were curious to probe what they were not interested in. Therefore, we listed the purpose why we selected the following four visuals as references. This might help us discuss the survey participants' motivation.

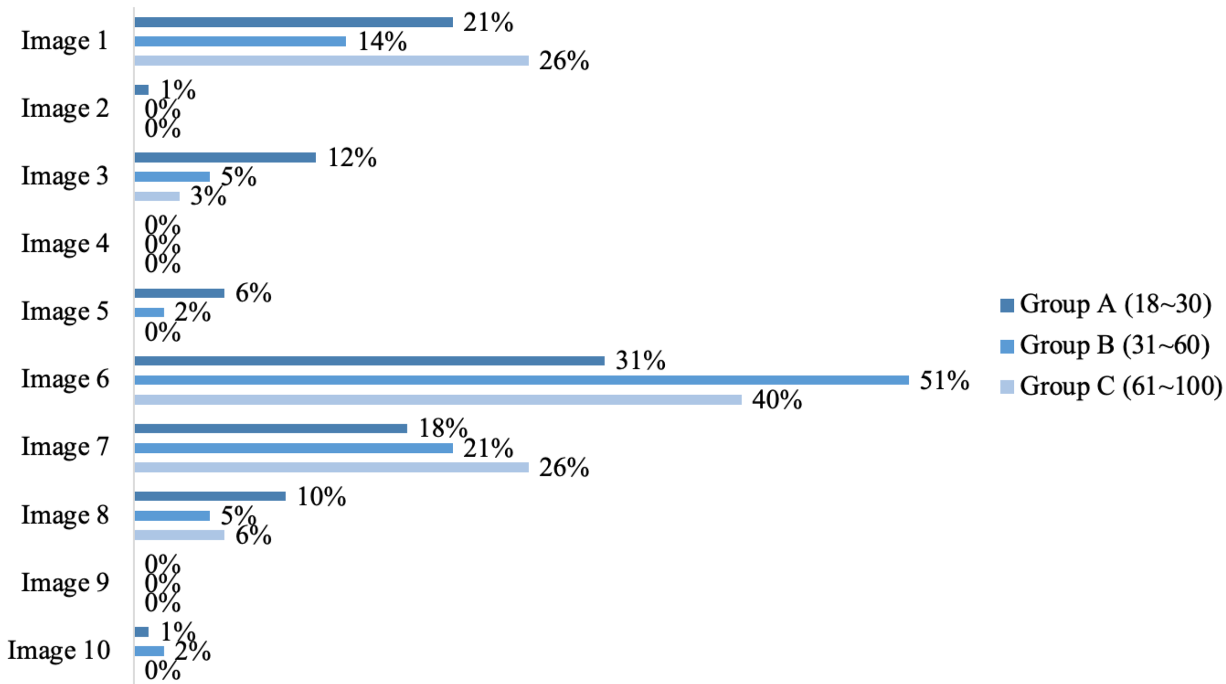
Image 2 is to present the comfort level people can feel when they lie on green grass to enjoy fresh air and sunshine, and get close to nature.

Image 4 presents a sense of peace, comfort, and calm for people walking in open spaces such as deserts. Participants can clearly see the bottom of people's feet, which indicates that the footwear wearing experience can make people feel clean, hygienic, dry (of the feet), or in a healthy condition.

Image 9 is to show people gathering, collaboration, family warmth, celebration, and contentment in life. We want to see if participants can feel an atmosphere similar to that inspired by the hot pot experience.

Image 10 represents speed, efficiency, momentum, and high performance for people walking in shoes. We want to see if survey participants have a similar experience or can resonate with their other life experiences. Regarding more detailed information, we documented the keywords that the survey participants used in Appendix I.

Figure 6.16. Please select the images that reflect the experience of your ideal indoor footwear. Select all that apply. (Appendix H: survey question 3.18.)

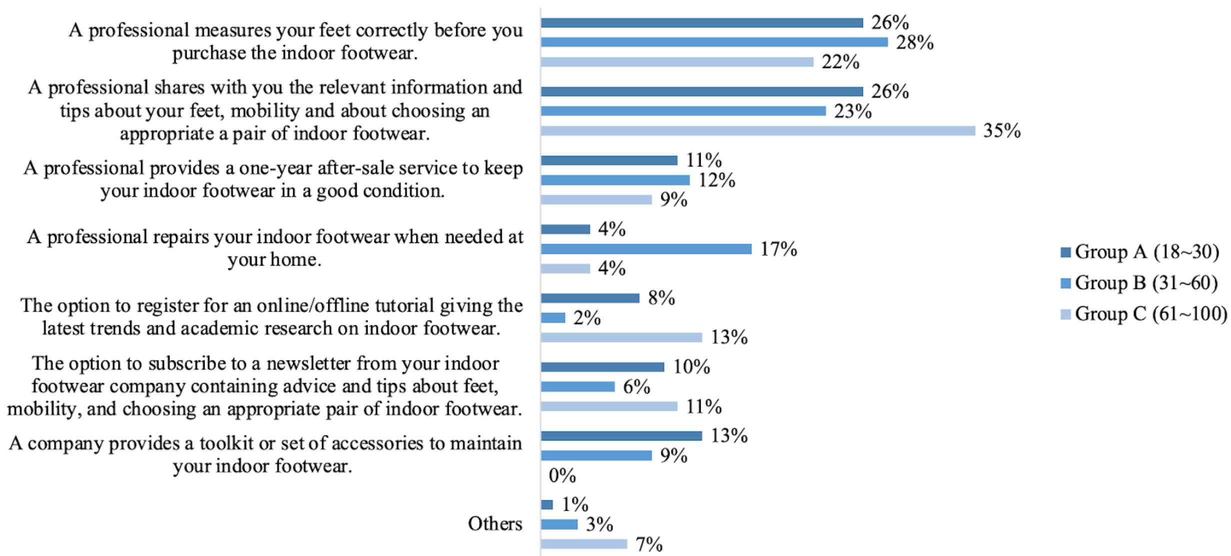


Envision Indoor Footwear Design: 35% of Group C would like to have their indoor footwear to provide the relevant information and tips about their feet, mobility, and choosing appropriate indoor footwear, which was very consistent with the result from Group A (26%) and B (28%). But we observed that older adults, Group C, selected their requirements of future footwear from the rest of the options (Figure 6.17.).

In general, Group A (26%), B (28%), and C (22%) desired to have a professional measurement of their feet correctly before purchasing indoor footwear. Similarly, all three groups also wanted to have a one-year after-sale service to keep their indoor footwear in good condition.

It was great to observe our survey participants envisioning their own future indoor footwear, which greatly helped us to understand some of the hidden user needs and pain points as preparation for the next stage of product and service design.

Figure 6.17. Imagine in the future if you were to have a pair of high-end or better quality indoor footwear, ideally, which professional services and experiences would you be most interested in having with regard to your indoor footwear? Select all that apply.
(Appendix H: survey question 3.29.)

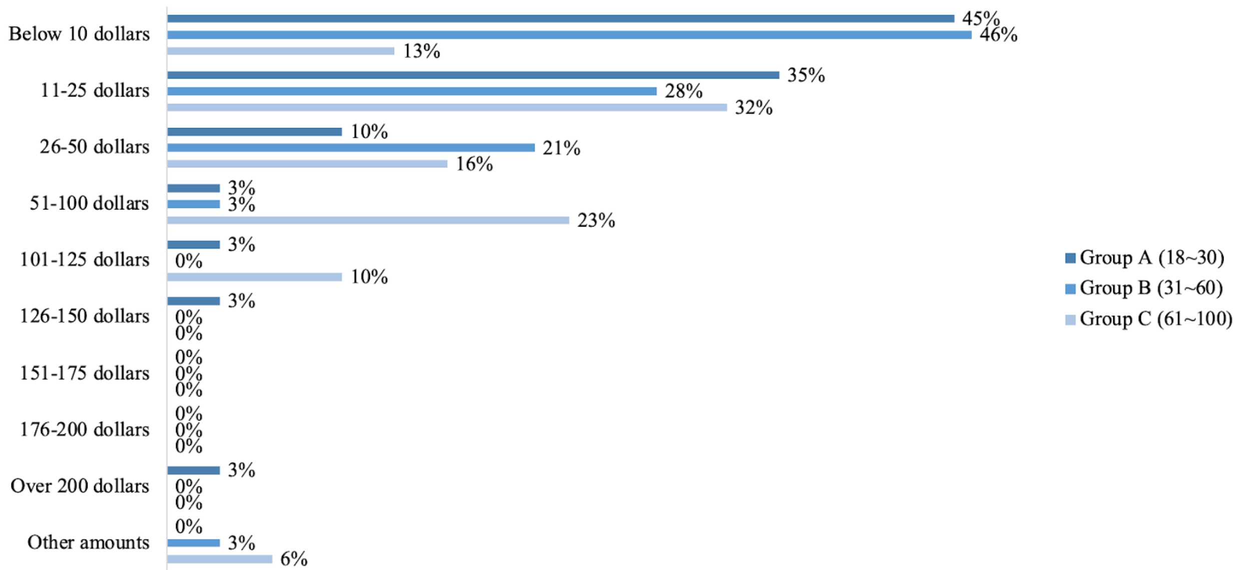


6.2.3. User's Purchasing Behavior

Price of Indoor Footwear: Figure 6.18. showed that in general close to half of Group A (45%) and B (46%) thought the suitable price for a pair of indoor footwear was below 10 dollars, whereas 23% of Group C thought 51-100 dollars was reasonable and 10% of Group C thought 101-125 dollars was OK.

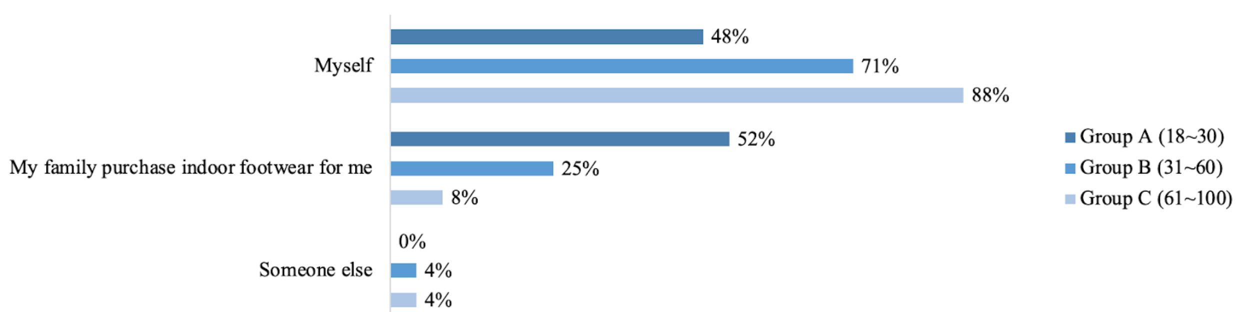
We were curious to know how the survey participants decide the price point of indoor footwear. Was it because of the number of practical functions that indoor footwear can provide? Was it because people view it as accessories? And how did the price connect with age?

Figure 6.18. What do you consider to be a suitable price for a pair of indoor footwear that you would purchase for yourself? Select all that apply. (Appendix H: survey question 4.2.)



Indoor Footwear Purchasing: Figure 6.19. helped us clarify who the key stakeholders purchasing indoor footwear were. Interestingly, 88% of Group C purchased themselves, whereas 52% of Group A was given by their family. We originally assumed the result was the opposite, since people tended to purchase gifts for their parents or grandparents. We guessed maybe in this context, indoor footwear was not so expensive that people viewed it as a gift, but was a normal necessary daily items.

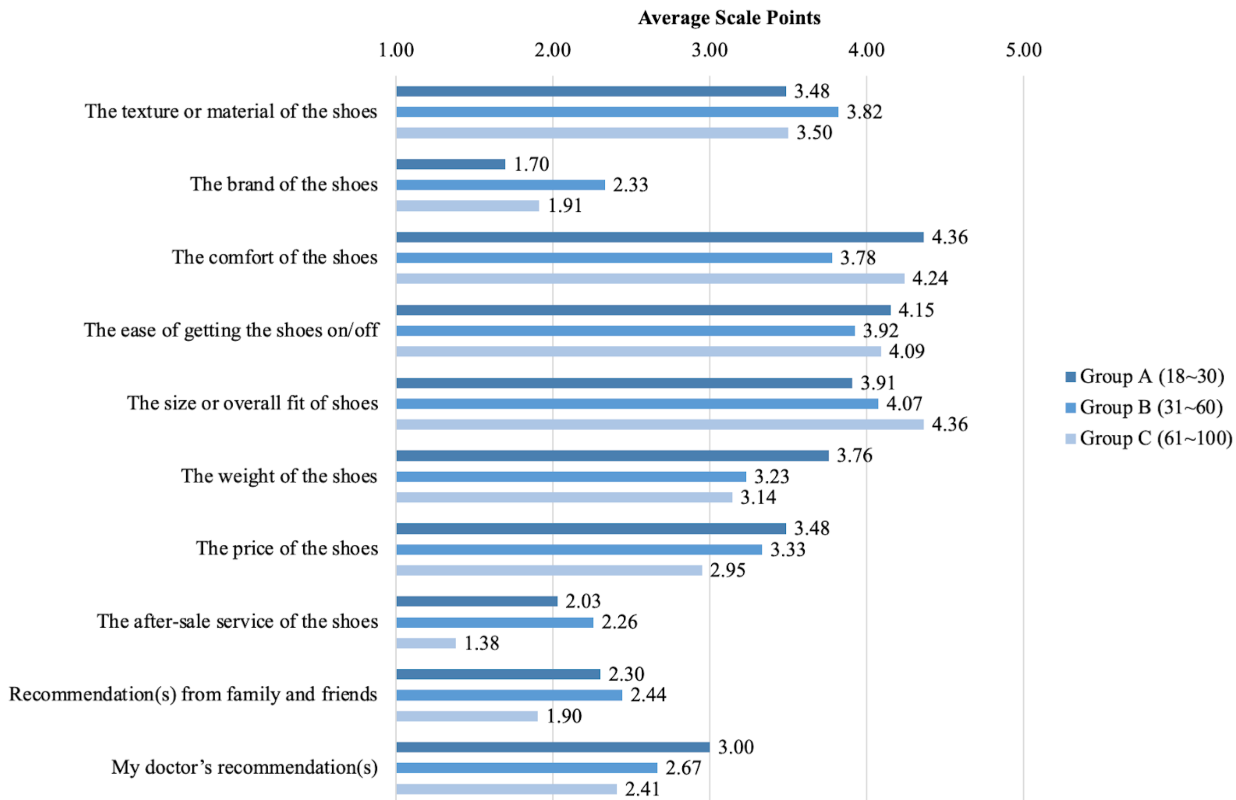
Figure 6.19. Who usually purchases your indoor footwear?
(Appendix H: survey question 4.3.)



Factors of Indoor Footwear Purchasing: Figure 6.20. showed the critical considerations for people in purchasing indoor footwear. We used a 5-point answer scale as a measurement framework where 1 means least important and 5 means that a factor is a critical criterion. The survey result exhibited that ten factors were selected comprehensively. Among these, the comfort level of the shoes mattered the most to Group A (4.36/5); the texture or material of the shoes was critical to Group B (3.82/5), and the size or overall fitness of shoes was the most important factor for Group C (4.36/5).

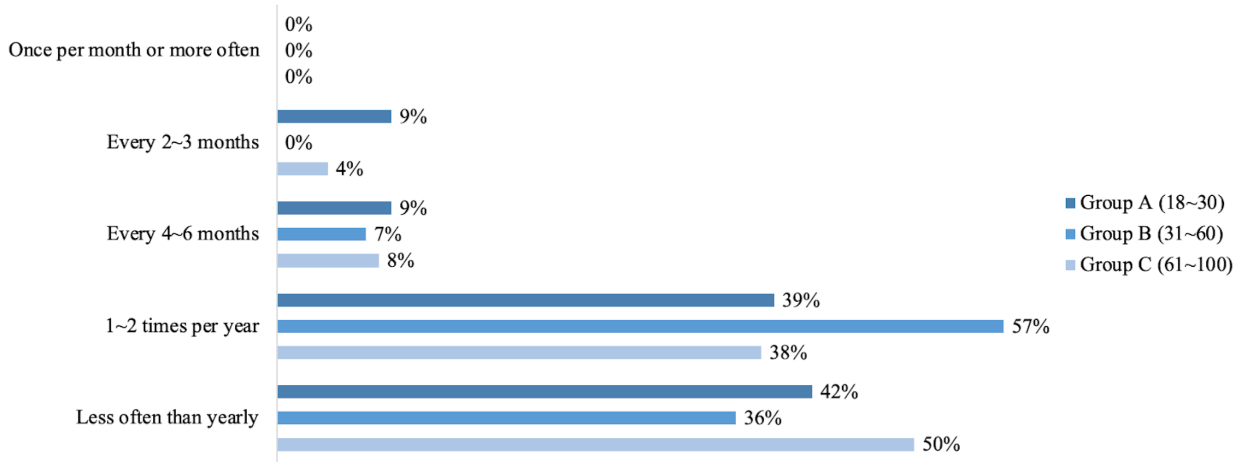
Options like "the brand of the shoes", "the after-sale service of the shoes", and "recommendations from family and friends" were relatively low. We wanted to know if it was because people didn't have trust in the brands (Figure 6.22.); or people hadn't had good footwear service experience before; or people's families and friends didn't know their needs of footwear; or there were other reasons we hadn't figured out.

Figure 6.20. How important are each of the following factors to you when you purchase indoor footwear? (Appendix H: survey question 4.4.)



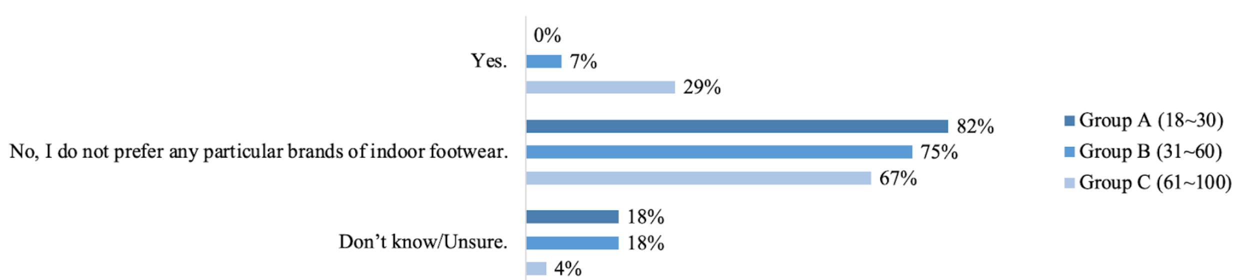
<u>Frequency of Indoor Footwear Replacement:</u> In Figure 6.21., 50% of Group C replaced their indoor footwear less often than yearly and 38% of them might replace 1-2 times per year, which had pretty similar behavior as Group A and B. Further research can discuss the relationship between the frequency of indoor footwear replacement, its price point, and key stakeholders (people who purchase shoes versus people who wear the shoes). We might get more in-depth discussion points in terms of people's behavior.

Figure 6.21. How often do you typically replace your indoor footwear?
(Appendix H: survey question 4.5.)



Brand Awareness of Indoor Footwear: In Figure 6.22., it was interesting to focus on 7% of Group B and 29% of Group C who responded "Yes" to discuss what indoor footwear brands they preferred to have or purchase. Since the price point of typical indoor footwear (e.g., slippers) was relatively low compared with sneakers and other shoes, normally people wouldn't mind spending money to purchase an extra. We might hypothesize that the brand awareness of indoor footwear was less sensitive if we assume the price correspondence with the brand awareness. Therefore, we thought this could be a huge business opportunity to explore and invest in some of the potential good brands of indoor footwear.

Figure 6.22. Do you prefer certain brand(s) of indoor footwear?
(Appendix H: survey question 4.6.)

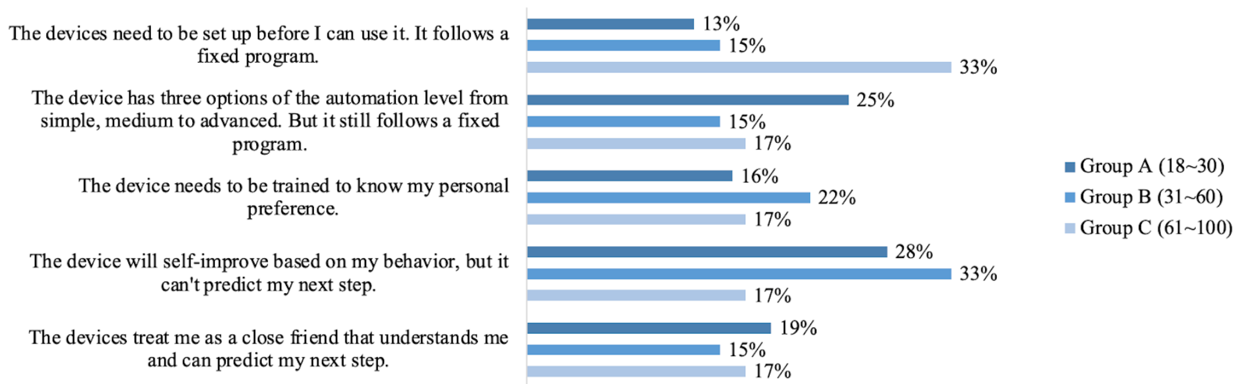


6.2.4. Smart Footwear Concepts

Automation Level of Smart Wearable Devices: Figure 6.23. showed that 33% of Group C showed significantly that they thought the devices needed to be set up before use. The device followed a fixed program. Group B also showed the same percentage (33%) that they thought the devices would improve by themselves based on their behaviors, but could not predict their next step, which was also the highest one for Group A (28%).

We hypothesized that people's mode of thinking to accept different levels of automation of smart wearable devices may lie in whether the devices can make decisions for people or with people. The root cause could be traced back to the importance of trust and transparency as possible key factors.

Figure 6.23. Given the various levels of automation that smart wearable devices can have, what level of automation would you be comfortable with your smart wearable devices?
(Appendix H: survey question 5.2.)



<u>*Data Privacy:*</u> According to research, we can define the concept of the Internet of Things (IoT) in a simple way: it is a physical object or thing embedded with technology (e.g., sensors) to exchange data with other devices or systems through the internet [141]. Figure 6.24. showed the level of data privacy from our survey participants. 50% of Group C didn't want their IoT wearable devices to store any of their personal data on the cloud. 30% of Group A felt somewhat comfortable, which was close to 32% of Group B.

Though data privacy and sensitivity issues might correlate with different age groups, we need to conduct more studies to support our assumption. In general, this result implied that older adults were less willing to share their information on the cloud. Table 6.4. exhibited survey participants' attitude towards data-related topics by completing the sentence: design with data means to______.

Figure 6.24. We want to know how comfortable you are with the idea of IoT wearable devices sharing the data they collect about you on the cloud.

(Appendix H: survey question 5.3.)

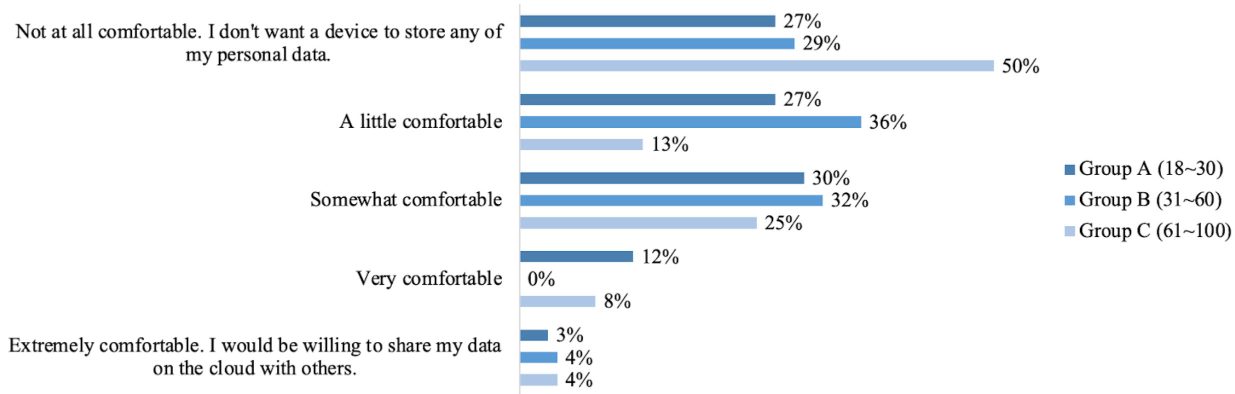


Table 6.4. Complete the sentence: designing with data means to_____________________.

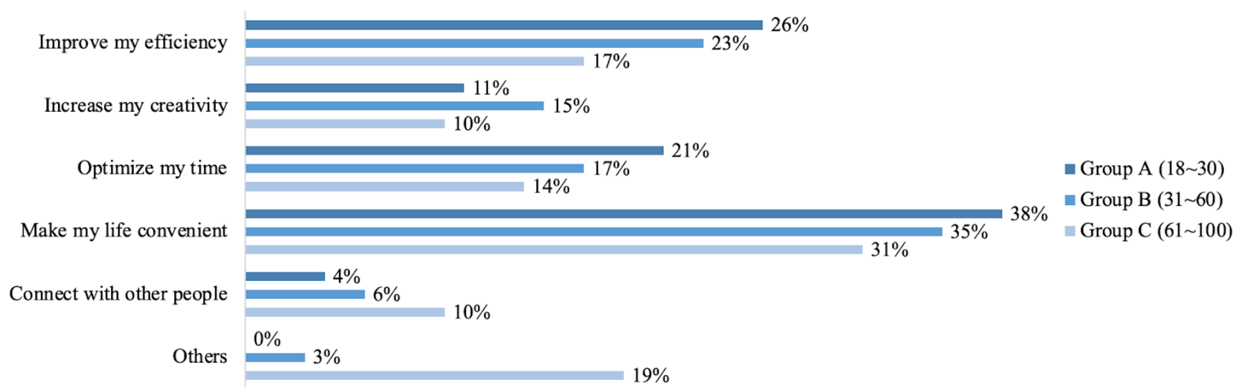
(Appendix H: survey question 5.4.)

Group A (aged 18~30)	**Group B (aged 31~60)**	**Group C (aged 61~100)**
Response	Response	Response
• big data • scientific • reliability • intelligent • visualization • easier to use • unsustainable • more accurate • get more details • understand user needs • digitalization • adjust the design with data • collect data to do better design • design according to users' habits • combination of technology and life • can provide personal recommendations • make proper interpretation and use of data • ability to customize the personnel data after data analysis • can make improvements and follow the needs of most people • sharing of personal information with the business or third parties • use the collection and integration of big data to predict the next step	• comfort • convenient • more accurate • know me better • fit people's habits • design in advance • artificial intelligence • health management • data as a design material • make me feel comfortable • suit me but know me more • customer behavior record • improve the user experience • the design came from reasons • more scientific and rigorous design • you can predict the behavior of users • make people's life more simple and easier • give users some reasonable suggestions • design according to target customers' needs • major trend, integration, data collection & high price • use data collected to design products suitable to the needs	• custom made • personalized fit • revolutionize footwear • build a tailor-made technology • enable users to have a suitable life • make things more complicated • provide more information to me • require data I may not wish to reveal • have a more comfortable indoor shoes • design with my particular requirements • translate the data into improved comfort and use • satisfy the needs of the wearer based on teeth • use technology to improve the human experience • make my shoes better but not share data with others • individualize products satisfying the needs of consumers • understand how to use the collected info/data to create better products for users • I do not want an AI device to

of customer needs and design accordingly ● the progress may be a little complex, because I think that the most important thing is to enjoy and to relax		create, design, monitor, or do anything else for me ● anticipate future actions/movements based on past recorded performance

Desired Functions of IoT Wearable Device: Not surprisingly, the result showed that making people's life convenient got the highest percentage (between 30% to 40%) among other options (Figure 6.25.). We also observed that 19% of Group C, older adults, selected "Others", which revealed that designers could have more room to play in fulfilling user's unmet needs.

Figure 6.25. Which of the following functions would you want an IoT wearable device (not just a pair of smart indoor footwear) to help you with? Select all that apply.
(Appendix H: survey question 5.5.)



Keywords Associated with Smart Footwear: Table 6.5. presented what the survey participants desired of the type of "smart footwear" in their minds through these keywords. We analyzed them and counted the number of keywords shown in their response. The top 3 keywords of each group were: technology (6 times), convenient (6 times), and comfortable (6 times), from Group A; healthy (8 times), convenient (4 times), data (3 times), and comfort (3 times) from Group B, and comfortable (5 times), safety (4 times), and comfort (4 times) from Group C.

Not surprisingly, most survey participants felt that smart footwear should make people feel healthy, comfortable, safe, convenient, and have a data-driven process with high technology components.

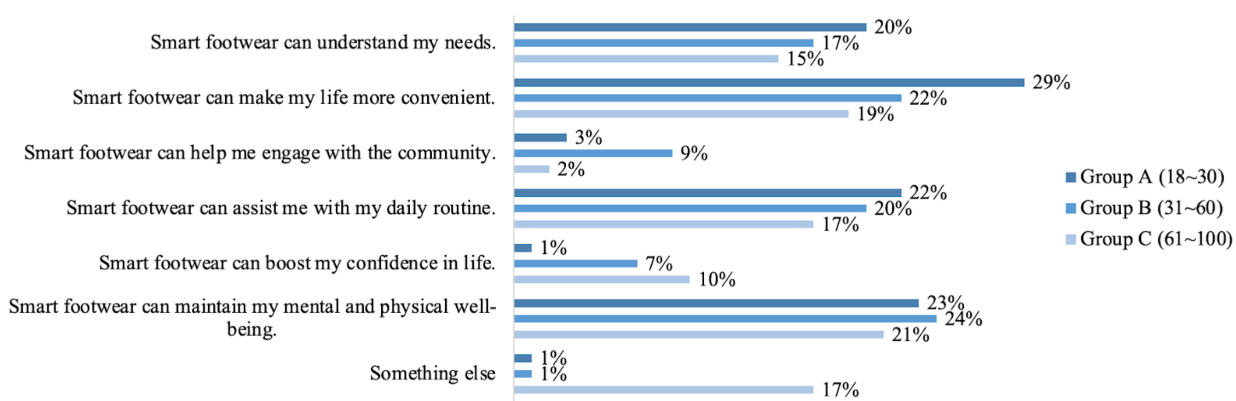
Table 6.5. What words come to your mind when you hear the term "smart footwear"? Please list 2 to 3 keywords.
(n means number of keywords shown, Appendix H: survey question 5.6.)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• technology	6	• healthy	8	• comfortable	5
• convenient	6	• convenient	4	• safety	4
• comfortable	6	• data	3	• comfort	4
• smart	4	• comfort	3	• fit	2
• expensive	4	• smart	2	• crazy	2
• efficient	3	• comfort	2	• health	2
• comfortable	3	• adjustable	2	• expensive	2
• personal	2	• comfortable	2	• convenient	2
• massage	2	• tracking and monitoring	2	• me	1
• advanced	2	• AI	1	• silly	1
• expensive	2	• 5G	1	• real	1
• life	1	• fast	1	• care	1
• new	1	• cool	1	• light	1
• safe	1	• price	1	• ease	1
• fast	1	• good	1	• smart	1
• cool	1	• smile	1	• future	1
• item	1	• clever	1	• action	1
• data	1	• happy	1	• stylish	1
• price	1	• safety	1	• helpful	1
• tired	1	• phone	1	• control	1
• sport	1	• mobile	1	• wearer	1
• voice	1	• electric	1	• warmth	1
• novel	1	• internet	1	• custom	1
• trend	1	• gesture	1	• relevant	1
• future	1	• ecology	1	• industry	1
• speed	1	• optimal	1	• accurate	1
• shoes	1	• efficient	1	• enhance	1
• health	1	• security	1	• intrusive	1
• suitable	1	• personal	1	• high tech	1
• internet	1	• machine	1	• inventive	1
• accurate	1	• fantastic	1	• not brainy	1
• scientific	1	• response	1	• unneeded	1
• complex	1	• know me	1	• ridiculous	1
• amusing	1	• high price	1	• unwanted	1
• analyzing	1	• save time	1	• interesting	1
• high-tech	1	• adaptable	1	• automotive	1
• convince	1	• interaction	1	• technology	1
• intelligent	1	• connection	1	• appearance	1
• auto wear	1	• battery risk	1	• complicated	1
• inquisitive	1	• adoptability	1	• complicated	1
• vulnerable	1	• customized	1	• voice control	1
• intelligent	1	• temperature	1	• unnecessarily	1
• innovative	1	• professional	1	• know my body	1
• customize	1	• personalized	1	• genuine leather	1
• humanized	1	• mind-reading	1	• multi-functional	1
• changeable	1	• universal design	1	• multitask worthy	1

considerate	1	know my behavior	1	an objective analysis of need	1
running fast	1	fit the requirement	1	improve balance to prevent falling	1
record steps	1	medical treatment	1		
unnecessary	1	environment friendly	1		
record weight	1	improving all the time	1		
unnecessaries	1	precise and adjustable	1		
growth with data	1				
smart size fitting	1				
no need to worry	1				
health monitoring	1				
autofit my foot size	1				
artificial intelligence	1				
knowledge awareness	1				
smart comfort adjusting	1				
collecting feet and body data	1				
sense of science and technology	1				

<u>*Desired Functions of Smart Footwear:*</u> Figure 6.26. revealed what people wanted in terms of their ideal indoor footwear functions. We were especially interested in the users' needs of Group C, older adults. They wanted smart footwear to maintain their mental and physical well-being (21%), make their life more convenient (19%), and assist them with their daily routine (17%). The top 3 features above gave us a great reference when we did brainstorming on the functions we want to integrate into smart footwear.

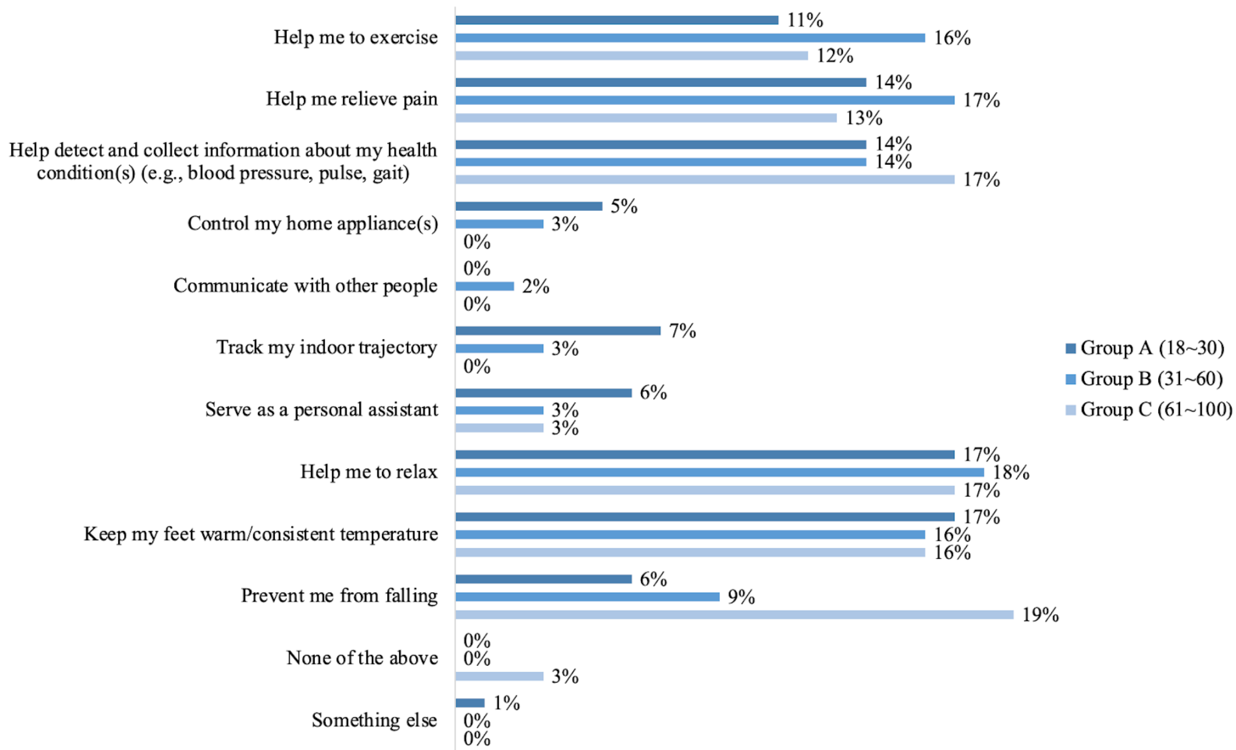
Figure 6.26. What sort of things do you think smart footwear could do for you? Select all that apply. (Appendix H: survey question 5.7.)



<u>*Desired Functions of Smart Indoor Footwear:*</u> In Figure 6.27., the top 3 functions that older adults, Group C, wanted to have were: prevent them from falling (19%), help detect and collect information about my health condition(s) such as blood pressure, pulse, and gait (17%), and help them relax (17%). Safety, healthcare, and relaxation were critical for older adults. Compared with the top 3 functions that the younger generation, Group A, wanted to have were: help them to relax (17%), keep their feet warm/at a consistent temperature (17%), and help them relieve pain (14%). Comfort and convenience were the main considerations for Group A.

Regarding the middle-age population, Group B was similar to the result as Group A. Their top 3 functions were: help them relax (18%), help them relieve pain (17%), and help them exercise (16%) as well as keep their feet warm/at a consistent temperature (16%).

Figure 6.27. If you had a pair of smart indoor footwear, what functions would you want the footwear to have? Select all that apply. (Appendix H: survey question 5.8.)



<u>*Desired Concept of Indoor Footwear:*</u> In the user survey, we used ten early-stage design concepts (Table 6.6.) to probe participants' feedback in terms of their interest, divided by five levels from not at all interested, slightly interested, moderately interested, very interested to extremely interested. We can observe the difference between groups (three different age ranges) and how it connects to their lifestyle, behavior, health conditions, hobbies, demographics, and family.

We made detailed documentation in Appendix E. to help us understand our users' unmet needs, pain points, and their vision of future indoor footwear design. In each design concept document sheet, we had concept illustration, concept description, participants' interest level diagram, and participants' anonymous feedback. The information above greatly helped us to not only capture participants' inspiration but also understand what product features people are interested in and how we can address their pain points accordingly.

We also compared ten different design concepts across three groups (Figure 6.28.) and found out that 29% of Group C liked Concept 2 the most, but they didn't like Concept 6 (0%) or 8 (0%). 21% of Group B liked Concept 4 the most, but none of them liked Concept 5 (0%) or 8 (0%). 21% of Group A liked Concept 2 the most as Group C, but they didn't prefer Concept 4

(0%) or Concept 8 (3%).

Table 6.6. Design concept overview (same as Table J.1. and illustrated by Sheng-Hung Lee)

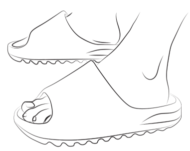
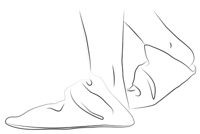
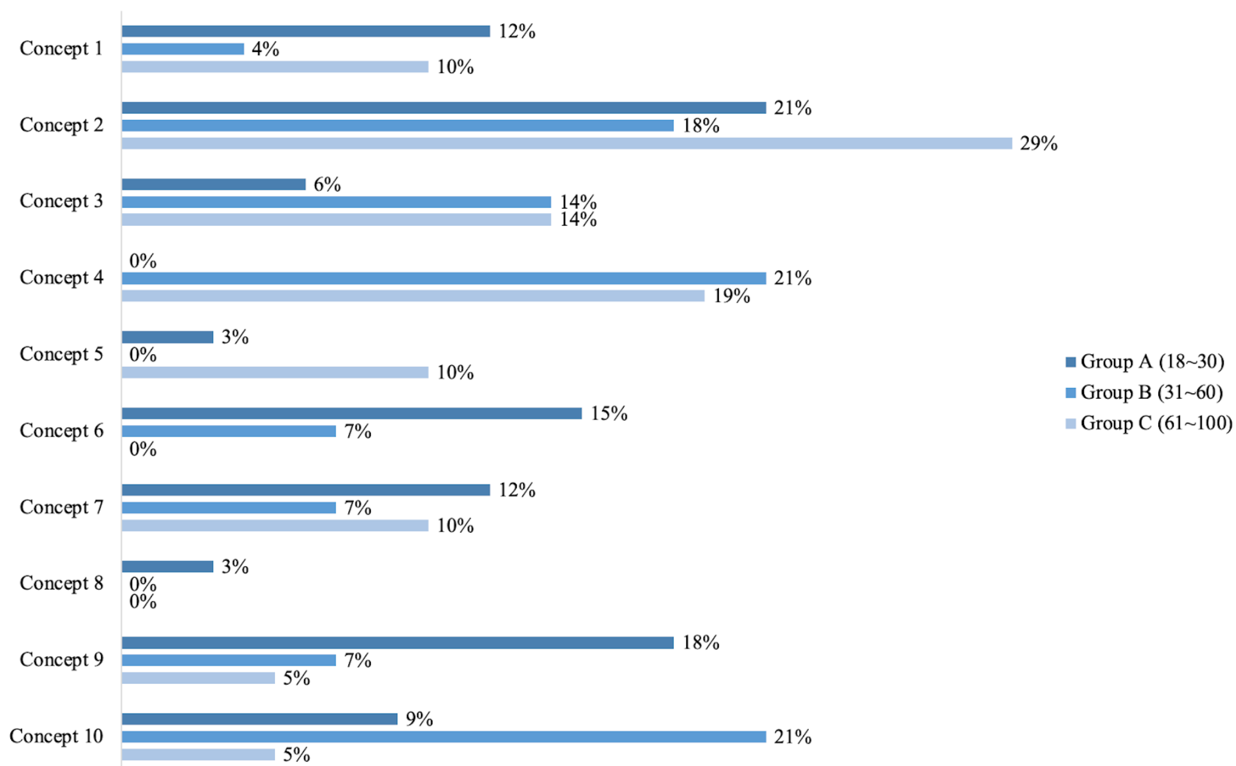
				
Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
				
Concept 6	Concept 7	Concept 8	Concept 9	Concept 10

Figure 6.28. If you were given one of these new pairs of footwear for free, which would you be most interested in? (Appendix H: survey question 5.30.)



6.3. Summary of User Survey

We had four key learnings from our user survey results. This section helped us understand the stories of our target user—older adults—and gave us a context to design for while integrating users' perspectives with care.

1) Pay attention to what people did not say instead of what they did say in research.

Frequently during user interviews, we observed some open-ended questions to which survey participants did not want to share their honest feedback. Or perhaps they did not know how to express their suggestions. For example, when participants shared that they want to have a comfortable pair of indoor footwear, we need to ask the follow-up questions to probe what they mean by the word "comfortable" and why this mattered to them. To get informative and critical first-hand interview materials, researchers and designers need to emphasize and decode what participants didn't want to touch or acknowledge.

2) Identify people purchasing indoor footwear that differ from people wearing them.

In the study, we needed to know whether the person who purchased indoor footwear was the same as the person who wore it From the survey results, most were aligned with the same person, but some groups were different (e.g., Group A was 52%, Group B was 25%, and Group C was 8%) (Figure 6.19.). Further research should consider how to design an adaptive user experience from purchasing, wearing, to after-sale service with different target users in the journey.

3) Build brand awareness and trust.

We realized that survey participants' brand awareness of indoor footwear was relatively low compared with other types of shoes (e.g., sneakers). Data are displayed in Figure 6.22. (0% of Group A, 7% of Group B, and 29% of Group C preferred certain brands of indoor footwear). This suggests indoor footwear brands have a great opportunity to target older adults and not only create well-designed products and establish a trustworthy brand name, but also build customer loyalty and trust.

4) Establish sustainable service and business models.

Figure 6.17. not only shows survey participants' vision of having an ideal pair of high-end or better quality indoor footwear, but also reveals that most participants lacked awareness and knowledge of the importance of indoor footwear service design. The seven options curated from Figure 6.17. included descriptions of future service design concepts, which did not fully resonate with the survey participants.

For example, we observed that Group A (26%), B (28%), and C (22%) desired a correct professional measurement of their feet before purchasing indoor footwear. Similarly, all three groups wanted to have a one-year after-sale service to keep their indoor footwear in good condition. Not surprisingly, these two options were expected or even already provided on the market. We expected that the other options would also be chosen from the participants more evenly.

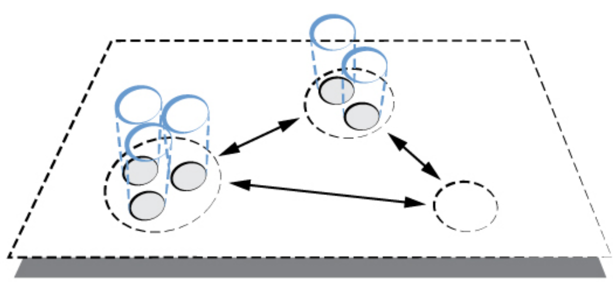
Chapter 7. Hybrid Participatory Workshop

7.1. Objectives and Research Questions of Hybrid Participatory Workshop

The goal of this master thesis project is to design better indoor footwear for older adults through the creative process, HCSD approaches, and academic research to help an aging population, their family, and their caregivers live a quality life. Hence, we want to use the hybrid participatory workshop as a new research medium and design methodology to explore the following three research questions.

1. How might we design an immersive hybrid participatory workshop experience that can inform and inspire participants across the globe to solve systemic social-technological design challenges? In this study, we focused on developing early indoor footwear design concepts.
2. How might we create a series of assistive toolkits e.g., workbooks, tutorials, devices, or services to facilitate the hybrid participatory workshop by empowering participants to have more transparent and interactive communication, build trust, and extend connections through their group discussion?
3. How might we involve the older adults during the hybrid participatory workshop to get their suggestions, ideas, or even their great design contributions in the building of future indoor footwear?

Figure 7.1. Conduct hybrid participatory workshops to co-create solutions
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



We also addressed some parts of the research questions and published the paper—Manufacturing Creative Impact: Co-creation Toolkits and Service Design for Remote Hybrid Collaboration Experience at the 8th Bandung Creative Movement 2021 conference hosted by Telkom University in Indonesia [33].

7.2. Hybrid Participatory Workshop Case Study

We had two case studies of hybrid participatory workshops. In this section, we define a "hybrid" workshop as one in which some participants are physically co-located while others join remotely. The two types of hybrid participatory workshop flows of two case studies are separately shown in Figure 7.2. and Figure 7.19.

To clarify the difference between the two case studies, we selected five measurable criteria: 1) benefit, 2) virtual section, 3) in-person activities, 4) facilitating tools, and 5) potential challenges, documented in Table 7.1.

Table 7.1. The demography of pre-workshop survey participants

	Case study 1	**Case Study 2**
Workshop topic	Rapid prototyping for footwear design	Envision the future footwear for an aging population
Number of participants	● Pre-workshop survey: 35 people ● Workshop participants: 21 people ● Post-workshop survey: 4 people	● 39 undergraduate and graduate students from several universities and colleges in the New England region e.g., MIT, Harvard University, Wellesley College, and Massachusetts College of Art and Design.
Collaborators	-ing Creatives (collaborated with Ziyuan Zhu, Ramy Alawssy, and Kateryna Petrovska [142])	MIT MediaLab Tangible Media group (course: MAS.834 Tangible Interfaces taught by Professor Hiroshi Ishii [127])
Workshop Date	November 7, 2020 (3-hour)	September 28, 2021 (3-hour)
Benefit	● Participants learn to build rapid prototypes designed for older adults. ● Participants learn to do storytelling around the footwear products they designed.	● Participants learn to conduct user interviews with older adults. ● Participants learn to do ideation/brainstorming with their team.
Virtual section	Virtual lecture and team discussion	Virtual interview with older adults
In-person activities	Make paper prototype by hand	In-person lecture and team discussion
Facilitation tools	Workbook [143], tutorials [144], and website [145]	Posters
Potential challenges	● How to elevate another level of prototype fidelity from paper-based models to electronic devices or even digital service experience? ● How to consider the format of a workbook beyond only providing prototyping instructions?	● How to follow up the conversion with interviewee from the workshop? ● How to help make the ideas generated from brainstorming sections to the next stage of the design process?

7.2.1. Case Study 1—Rapid Prototyping for Footwear Design

1) Set up goals and purpose.

The hybrid participatory workshop—Rapid prototyping for footwear design [129] partnered with -ing Creatives [142] over four-months of preparation, brainstorming workshop flow and content, target participants and their learning objectives, delivery of prototype materials, and timing the workshop to accommodate global participants. The design workflow is exhibited in Figure 7.2.

Our goal was to address the above three research questions in the section. Meanwhile, during the pandemic, we also wanted to leverage the resources from both MIT and -ing Creatives to explore new and creative ways to conduct the hybrid participatory workshop emphasizing the product and service prototyping phase during the design thinking process. For example, we wanted to empower workshop participants to build their footwear design out of paper and the service model e.g., Apps according to the persona they were assigned in the workbook. The participants can still experience the prototyping phase by hands during the pandemic.

Figure 7.2. The flow of the hybrid participatory workshop
(illustrated by Sheng-Hung Lee)

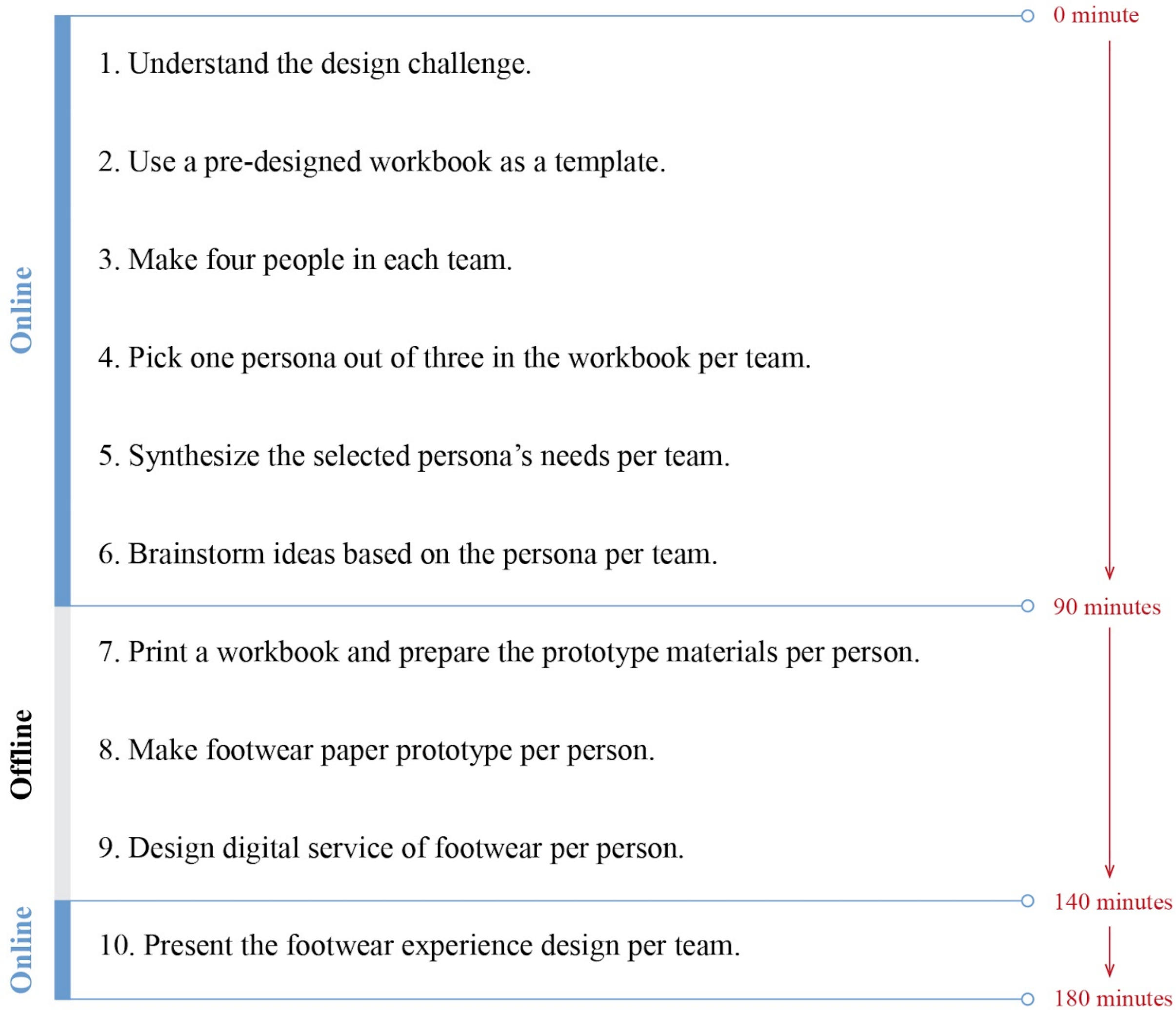
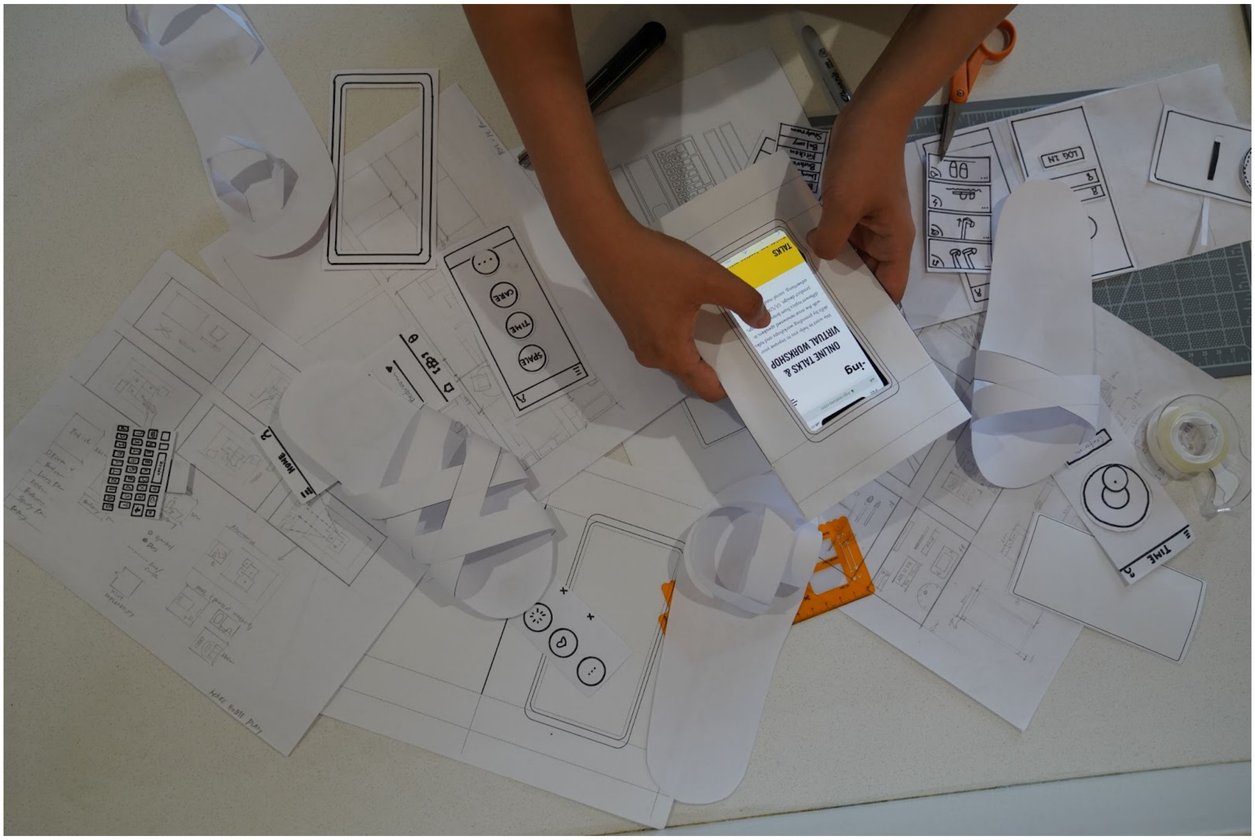


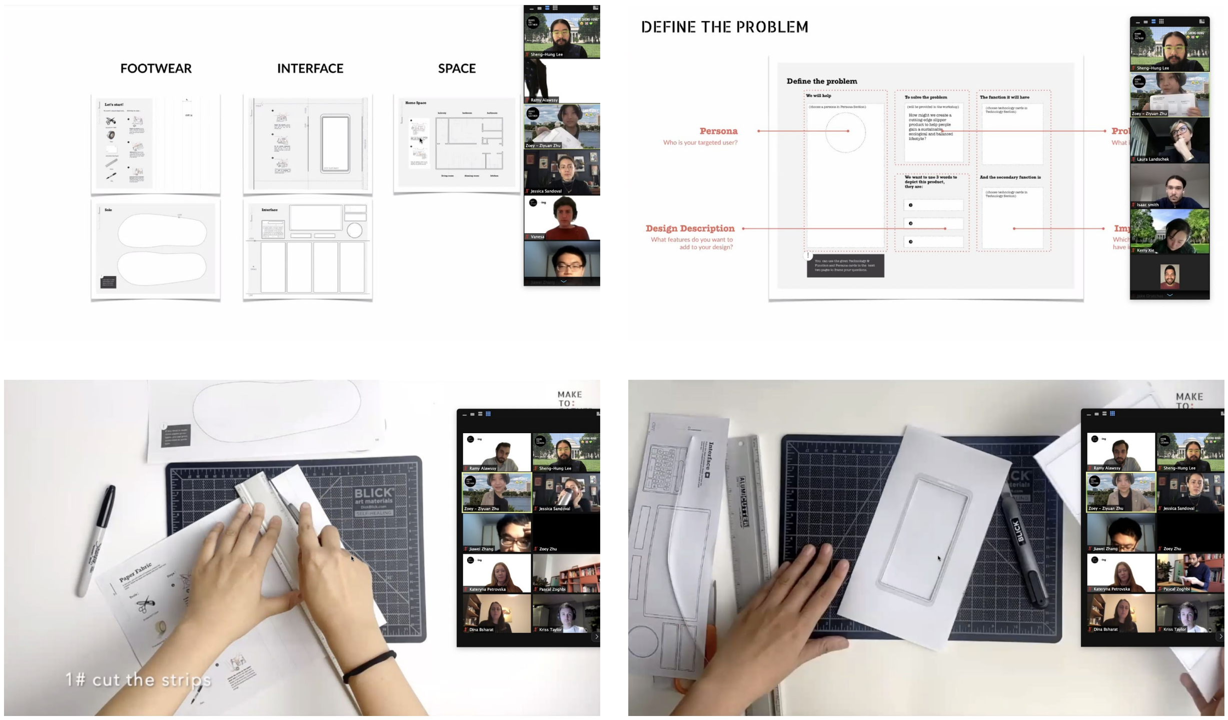
Figure 7.3. Test the hybrid participatory workshop workbook to make paper footwear and digital interface following the instructions on the website tutorial or workbook
(photo credit: Sheng-Hung Lee and Ziyuan Zhu)



2) Build an interactive workbook as a guide for making the prototype.

Due to the pandemic, high shipment cost, and limited time we had, we could not ship most prototype material e.g., foam core board, scissors, glue, Post-its, and thick colored paper, to our participants around the globe. Therefore, we created an interactive workbook [143] with clear instructions with visuals and a pre-designed paper prototype template, which the workshop participants could download and print out before the workshop started (Figure 7.4.).

Figure 7.4. Design an interactive workbook and tutorial for the hybrid participatory workshop (photo credit: Sheng-Hung Lee and Ziyuan Zhu)



<u>*3) Use a pre-workshop survey and post-workshop survey as an ice-breaking exercise.*</u>

To have a better immersive participatory workshop experience, we specifically designed the pre-workshop survey (n=35) and post-workshop (n=4) survey to help us understand participants' learning objectives, background, expertise, and expected outcome of the workshop. We also leveraged two surveys to connect to our participants as a virtual ice-breaking exercise.

From the pre-workshop survey result (Table 7.2.), we received 35 responses within a week and categorized the result into four groups by age range, where they were 51.4% male and 48.6% female. Participants were from the United States (22.8%), China (14.3%), United Arab Emirates (11.4%), Canada (5.7%), Germany (5.7%), and eleven other countries. A total of 37.1% of them were students, and 28.6% were trained as designers. More than half of the participants (57.1%) were between the age of 21 and 30 years old and 31.4% were in the age group of 31 to 40 years old.

We also observed that 28.6% of participants had no design skills and 17.1% were equipped with professional design skills; 25.7% considered themselves in between no design skills and professional design skills. Table 7.2. presents the details of the pre-workshop survey result.

Table 7.2. The demography of pre-workshop survey

	Group 1	Group 2	Group 3	Group 4
Age Range	21~30 years old	31~40 years old	41~50 years old	51~60 years old
Number of Participants	n = 20	n = 11	n = 3	n = 1
Percentage (total n=35)	57.1%	31.4%	8.6%	2.9%
Gender	Male (51.4%), Female (48.6%)			
Countries	United States (22.8%), China (14.3%), United Arab Emirates (11.4%), Canada (5.7%), Germany (5.7%), Belgium (2.9%), Taiwan (2.9%), Japan (2.9%), Spain (2.9%), United Kingdom (2.9%), Denmark (2.9%), Netherlands (2.9%), Republic of South Korea (2.9%), France (2.9%), Argentina (2.9%), and Kuwait (2.9%)			
Occupations	Student (37.1%), Designers e.g., product, graphic, branding, type designer (28.6%), Leadership Consulting (8.6%), Inventor (5.7%), Private Banking Associate (5.7%), Researcher (2.9%), and Managing Director (2.9%)			
Design Level	1 (28.6%), 2 (11.4%), 3 (25.7%), 4 (17.1%), 5 (17.1%) Note: Scale 1 is for people with no design skill, whereas scale 5 is for people with professional design skills.			

4) Understand participants' motivation to join the hybrid participatory workshop.

We were curious about what prompted them to participate in this hybrid co-creation workshop and why it mattered to them. Some participants said they were intrigued specifically by the prototype phase during the product design and development process to increase their proficiency in design and creation. "I've always been intrigued by the prototype process, from ideation to building something tangible. It's also an opportunity to be creative in a completely new way and I believe I'll learn a lot," said one participant.

Other participants felt that prototyping was important in their work, and therefore they would love to learn technical skills and integrate them into their work. "Prototyping is important for my work and I want to learn more about the prototyping process than the outcomes," said one participant. People also said, "Learn more about the techniques of other designers. Remove the stigma that a prototype is difficult."

"I'm excited with the possibility of working with a smart and creative group for an opportunity to think about how we interact with devices and systems that will become increasingly important in our lives," said one survey participant. The new hybrid ways (online lecture/offline making) to conduct a participatory workshop motivated some people to reflect on what had been transformed in the process of creatives and design thinking approach, echoing the one written in the pre-workshop survey, "Sometimes I find my mind stiff during ideation, I'd like to 'loosen it up' so I can allow more ideas to come."

We were also amazed that some participants were eager to learn the participatory workshop skill to apply to their own domain. There were at least three responses that showed their strong intention to learn this co-creation design capability:

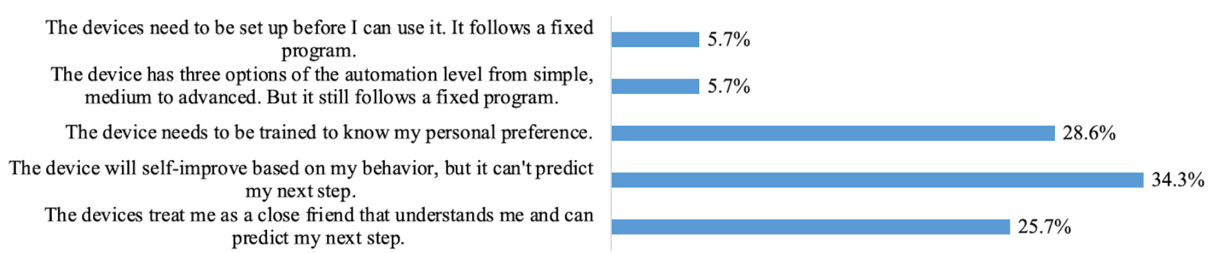
- "I am interested in bringing co-creating approaches to the design of large, complex socio-technical systems such as nuclear reactors, fission, and fusion."
- "I am highly interested in IoT design, and hope to learn how to do the rapid prototype through this workshop and develop my own design afterward."
- "I have a technical background majoring in computer science. I have always had the dream of becoming a designer. I hope to learn some design skills which may help me to become a user experience designer in the future."

5) Analyze the pre-workshop survey.

Automation Level of Smart Wearable Devices: The smart wearable device containing a level of "smartness" would be popular for the participants. As Figure 7.5. shows, 34.3% of participants wished the device would self-improve based on their behavior, but didn't want it to predict their next step; 28.6% of them were in the neutral option, whereas 25.7% of them felt that their devices should treat them as close friends that understood them and could predict their next step.

Comparing the survey result with Figure 6.23. (survey question 5.2) in Section 6.2.4., 33% of Group C (61~100 years old) loved the least automated option: The devices need to be set up before they can use them. It follows a fixed program. In further studies, we could explore the concerns people have in terms of technology use, cognitive constraints, physical limitations, social norms, or pressure that made older adults prefer the least automated option.

Figure 7.5. Given the various levels of automation that smart wearable devices can have, what level of automation would you be comfortable with your smart wearable devices?
(n=35, Appendix K: survey question 2.1.)

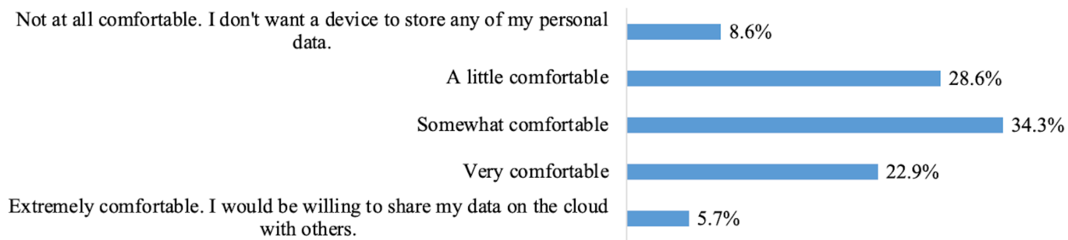


Data Sensitivity of IoT Wearable Device: Figure 7.6. shows that 34.3% participants felt somewhat comfortable (neutral) if their data was stored on the cloud while using IoT wearable devices. The diagram almost perfectly demonstrated a normal distribution curve. In the survey question, we didn't specifically mention indoor footwear design for older adults, because we wanted to know people's perception of data privacy topics in general before discussing our indoor footwear product.

Compared with Figure 6.24. (survey question 5.3) in Section 6.2.4. of the option of somewhat comfortable, 30% of Group A (18~30 years old), 32% of Group B (31~60 years old), and 25% of Group C (61~100 years old) felt neutral. This participant pre-workshop survey consisted of 57.1% of Group 1 (21~30 years old) and 31.4% of Group 2 (31~40 years old), where their age range was weighted toward the younger and middle age generation as Group A and Group B. Therefore the percentage of option "somewhat comfortable" 34.4% was pretty close to 30% of Group A, and 32% of Group B.

Figure 7.6. We want to know how comfortable you are with the idea of IoT wearable devices sharing the data they collect about you on the cloud.

(n=35, Appendix K: survey question 2.2.)



<u>*The Relationship Between Data Value and Design Process:*</u> Besides knowing the participants' comfort level around data collection, we were curious to know their interpretation of the connection between the design and data. Therefore, we created an open-ended sentence, "Designing with data means to____" as a prompt to learn their impression (Table 7.3.).

It was interesting to see people use vivid metaphors to discuss the importance of using data during the design process. For example, someone said designing with data means to have peanut butter with jelly! Or as someone shared, "It is like a must for a useful product, but the action or process of designing with data must not be irritating to users. Especially in the digital age, designers or engineers need to have data to back up the design decisions."

Leveraging the value of data during the design process helped users have a better product experience. "Designing with data means to use data-driven designs to improve user experience," said one participant. Another participant also reminded us to understand how people want to receive their own data, and research what kind of behavior change can incentivize people to make the change actionable.

If we also view the survey result from Table 6.4. (survey question 5.4) in Section 6.2.4. we can have more comprehensive views on this question.

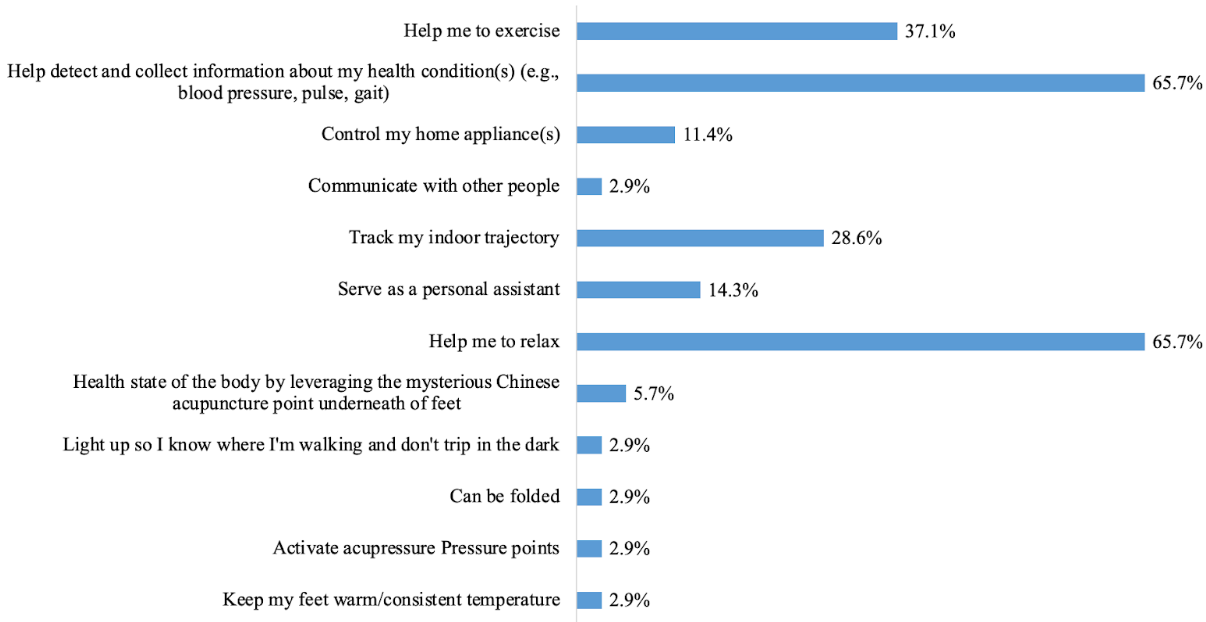
Table 7.3. Complete the sentence: Designing with data means to____________________.
(Appendix K: survey question 2.3.)

- organize the chaos
- paint with music
- make informed choices
- walk a privacy/security minefield
- know where the boundaries of your page are
- develop a superpower, which is difficult but rewarding
- have peanut butter with jelly! (In this digital age, you need data to back up your design decisions.)
- race with jet fuel
- design bespoke, and individual-specific artifacts
- like a guitar with an amplifier (Any action would be enhanced/evolved, no matter good or bad.)
- build the house according to the drawings
- lay tracks for the train
- know your market with targets
- like an adventure
- give a banana to a monkey
- like a must for a useful product (But it must not be irritating.)
- walk around your familiar neighbor on Sunday mornings
- like data-driven design to improve user experience
- drive with GPS
- drive with a map (You could discover many unknown things on the paper, but might also neglect something in the real world.)
- like a craftsmanship
- drive around a city with sat-nav
- publish journals with references
- be sensitive
- design with solutions
- see invisible dimensions of ourselves
- design with only the "What"
- think before speak
- understand how people want to receive data, and research what behavior change you want to make actionable
- create music in an MRI machine
- have too much info
- like the only way to design
- be prepared

Ideal Smart Indoor Footwear Design: The top four options that participants selected in Figure 7.7. were: detect health conditions (65.7%), make people relax (65.7%), help people do exercise (37.1%), and track in-home trajectory (28.6%). Although the options in Figure 7.6. were a bit different, it was still valuable compared with Figure 6.27. (survey question 5.8) in Section 6.2.4. to see whether there was any common ground to analyze.

In Figure 6.27., Group A (18~30 years old) and B (31~60 years old) showed similar interests in detecting health conditions (14%) and making people relax (17%~18%); whereas Group C (61~100 years old) were most interested in the indoor footwear functions to prevent them from falling (19%) and to help detect and collect information about their health condition(s) e.g., blood pressure, pulse, gait (17%).

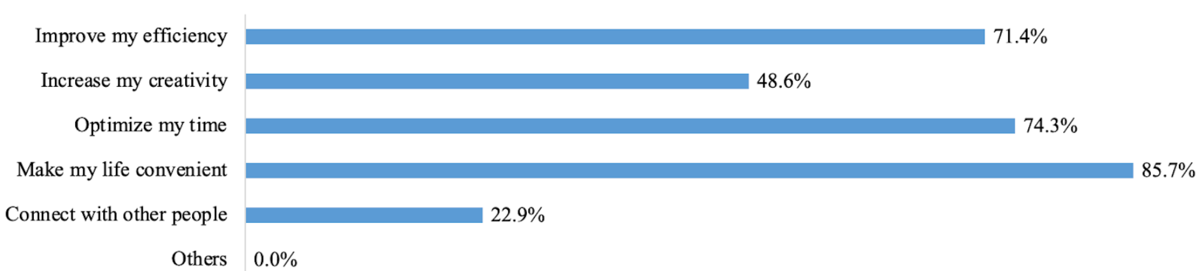
Figure 7.7. If you had a pair of smart indoor footwear, what functions would you want the footwear to have? (n=35, Appendix K: survey question 2.4.)



<u>Ideal IoT Wearable Device Design:</u> Besides designing ideal smart indoor footwear for older adults, we extended the survey questions further to discuss the functions of IoT wearable devices in general that users wanted to support in life (Figure 7.8.): 85.7% of participants wanted the IoT wearable devices to make their life convenient, 74.3% of them hoped the devices could optimize their time, and 71.4% of them wished the devices could help improve their work efficiency.

Compared the result with Figure 6.25. (survey question 5.5) in Section 6.2.4., surprisingly, 38% of Group A (18~30 years old), 35% of Group B (31~60 years old), and 31% of Group C (61~100 years old) all considered the option of making my life convenient the most critical among the options.

Figure 7.8. Which of the following functions would you want IoT wearable devices (not just a pair of smart indoor footwear) to help you with? (Appendix K: survey question 2.5.)

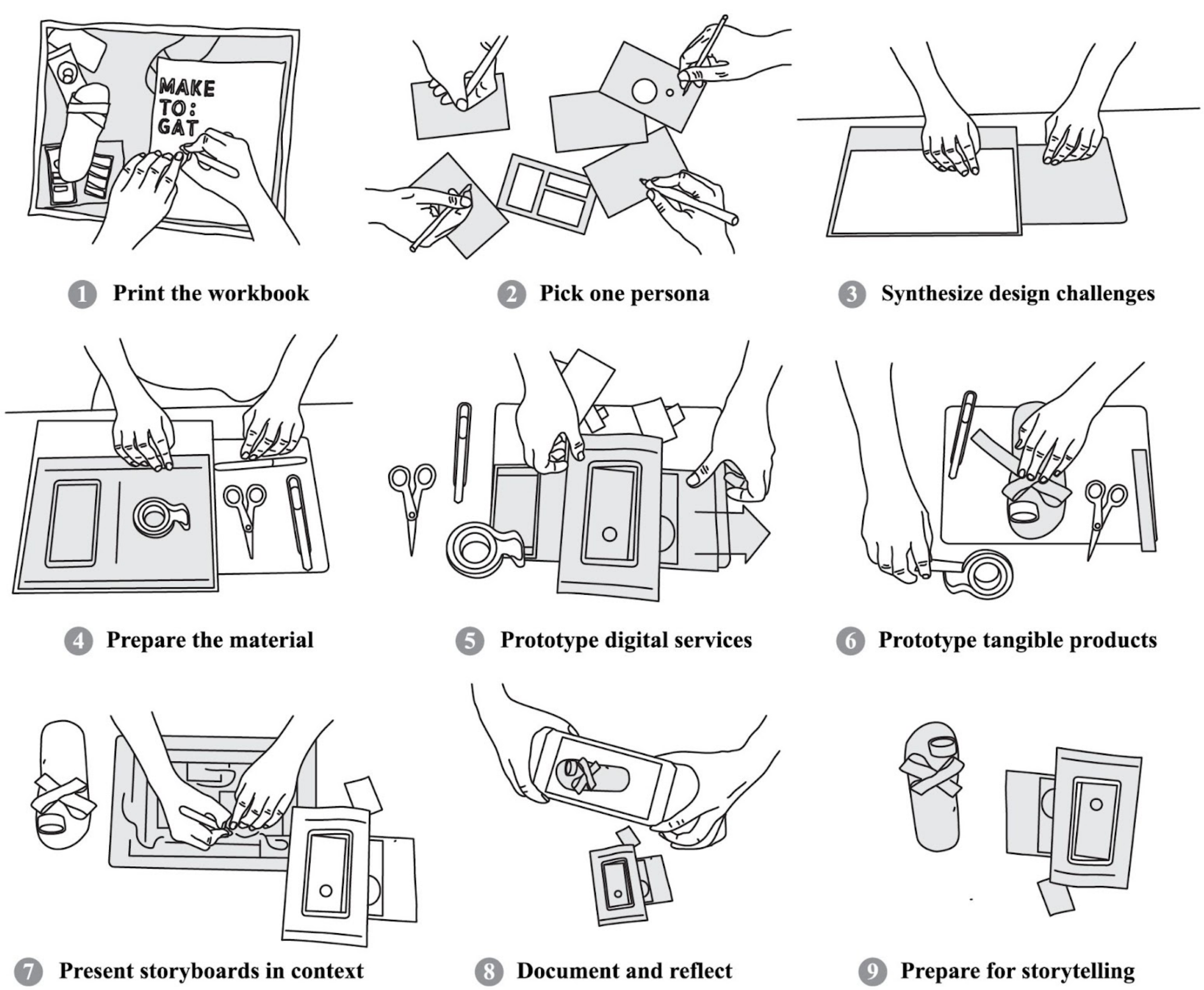


6) Host the hybrid participatory workshop.

In this section, we focus on nine steps of how to make footwear prototypes out of cardboard paper templates that were predesigned in the workbook. The design intention is to make the workshop participants experience the concept of rapid prototyping by using paper as an accessible medium/material to learn from making. This engaging session of design making is one of the highlights of the hybrid participatory workshop.

The following steps pair with the visual cues shown in Figure 7.9: 1) print the workbook, 2) pick one persona, 3) synthesize design challenges, 4) prepare the material, 5) prototype digital service, 6) prototype tangible products, 7) present storyboards in context, 8) document and reflect, and 9) prepare for storytelling.

Figure 7.9. Nine steps of making a footwear prototype out of paper material
(illustrated by Sheng-Hung Lee and Ziyuan Zhu)



To have a clear big picture of the overall flow of the hybrid participatory workshop, we combine the steps of making in Figure 7.9 and three key guiding principles: 1) THINK, 2) MAKE, and 3) SHARE in Table 7.4. with Figure 7.2. (Figure 7.10.).

Figure 7.10. The overall flow of the hybrid participatory workshop with making session
(illustrated by Sheng-Hung Lee)

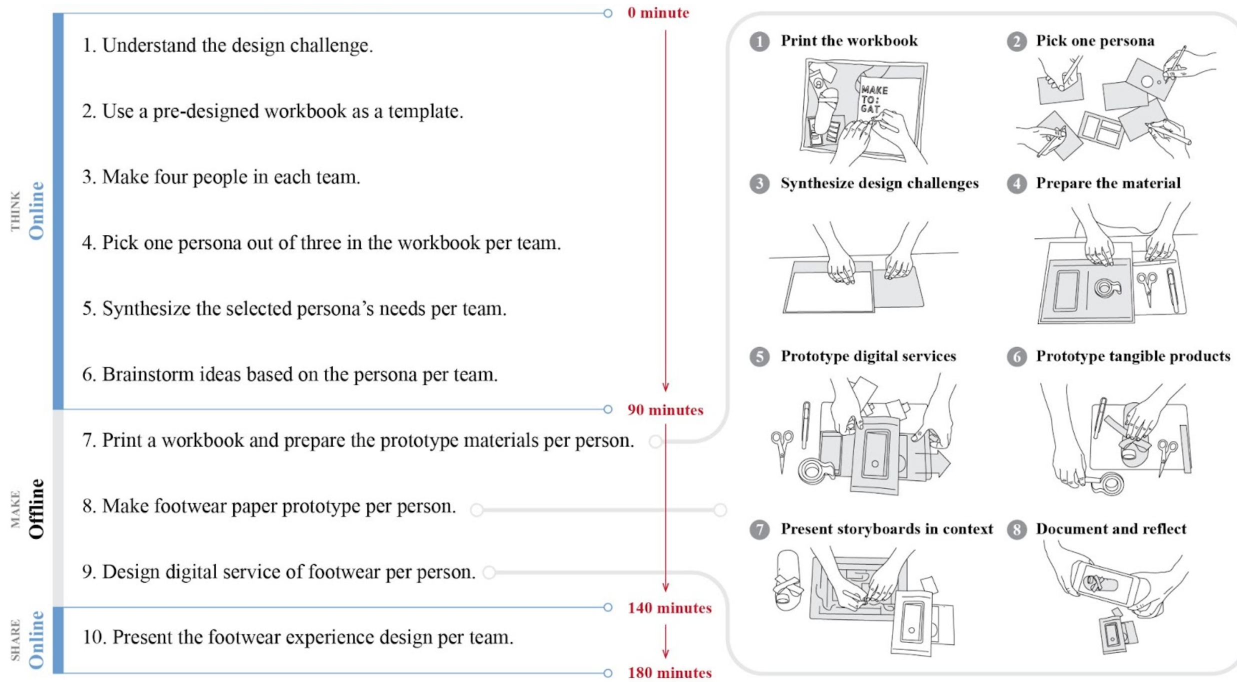
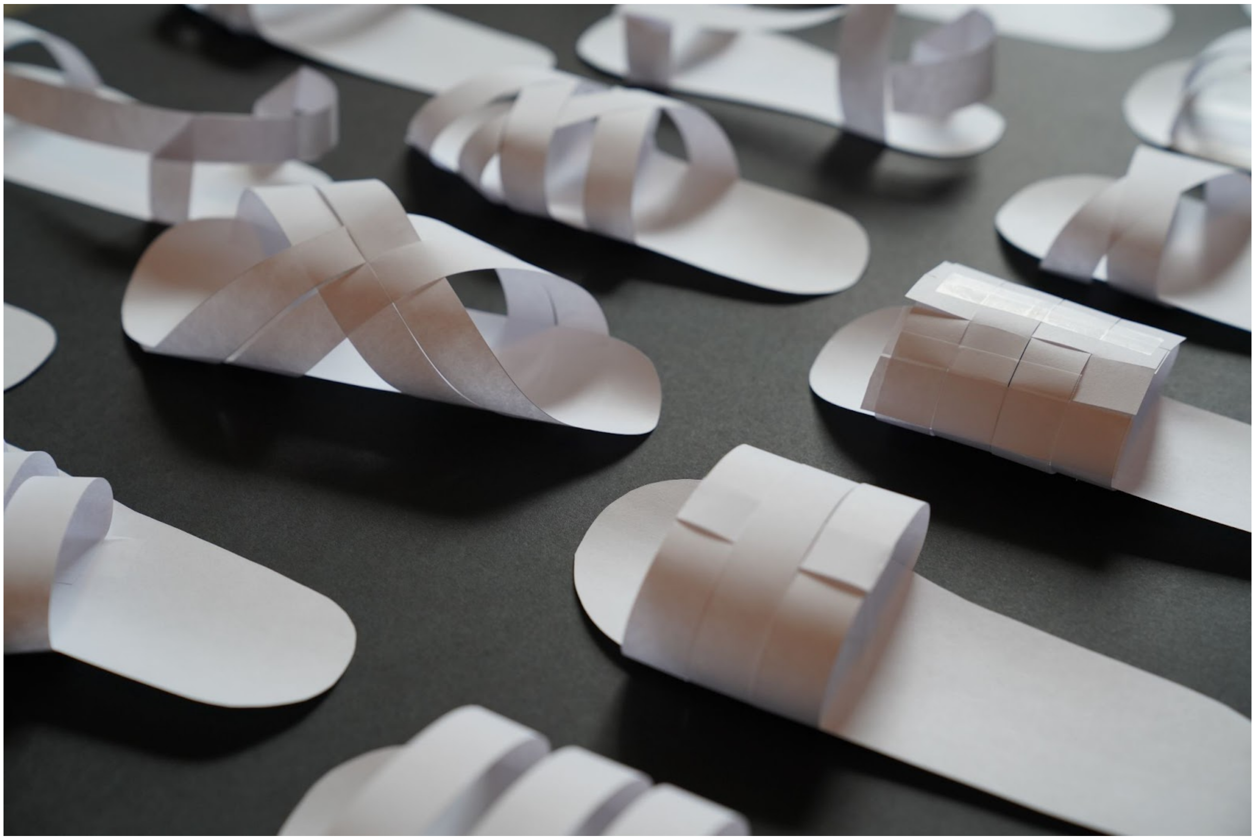


Figure 7.11. Prepare paper prototype material for the hybrid participatory workshop.
(photo credit: Sheng-Hung Lee)

Figure 7.12. Create and test a series of paper footwear prototypes.
(photo credit: Sheng-Hung Lee)



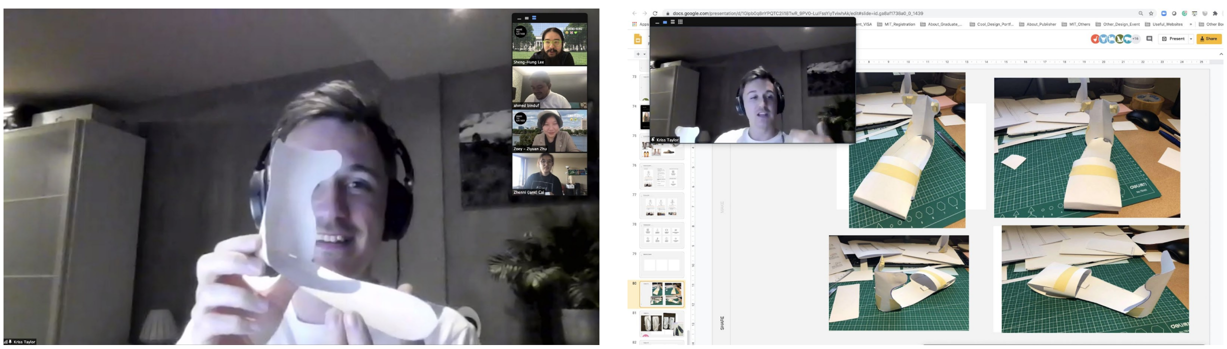
Three key steps of their explanations and instructions—THINK, MAKE, and SHARE—were documented in the workbook shown in Table 7.4. These steps were also the flow of the hybrid participatory workshop. Our intention was to design a workshop workbook to make the content crystal clear and all the steps easy to follow for our participants.

Table 7.4. The workbook covers instruction on the three key steps of the hybrid participatory workshop. (organized by Sheng-Hung Lee and Ziyuan Zhu)

Step	Brief explanations	Instructions
1. THINK	The THINK section aims to help participants understand the design challenge according to their persona and assist them to quickly generate tons of ideas and concepts and share them with their teammates. Before participants start brainstorming, they each need to read the persona cards carefully to know his/her frustration and the problem he/she might face. Next, participants reframe the design challenge we provided combining their observation and insights about the persona they chose.	1. Reframe the design challenge according to the persona's needs and pain points of participants. 2. Find inspiration materials for participants' design by creating mood boards. 3. Generate lots of ideas with the participants' team.
2. MAKE	In the MAKE section, participants will engage in how to make the rapid prototype. As participants have already printed all the materials they need, we invite them to follow the steps to start	1. Make meaningful rapid IoT product prototypes with guidance. 2. Consider the data and technology parts

	their "MAKE" journey with their hands and minds. Though we provided detailed instruction to help participants start the making process, we encourage them to add extra components and their imagination in the creative journey. When participants create the slipper part for the users/persona, they need to think about the behavior of the user.	and implement them into your IoT product design. 3. Connect participants' IoT product design with space.
3. SHARE	In the SHARE section, we will help participants to create a beautiful and meaningful story for their design with the team. We encourage them to start creating scenarios in four scenes, but they are welcome to add more scenes to fit their design concepts. SHARE is a teamwork session. Participants will share their ideas with team members before they start discussing teams' stories. After participants finish their storyboard, they need to take photos of their design and create the storytelling panel to share with us.	1. Make a storyboard with your team based on participants' product and interface design. 2. Refer back to participants' design challenge and selected persona to evaluate their storyline. 3. Take photos and document participants' final design deliverables.

Figure 7.13. The workshop participants present their future footwear ideas and paper prototypes emphasizing on product innovation. (photo credit: Sheng-Hung Lee)



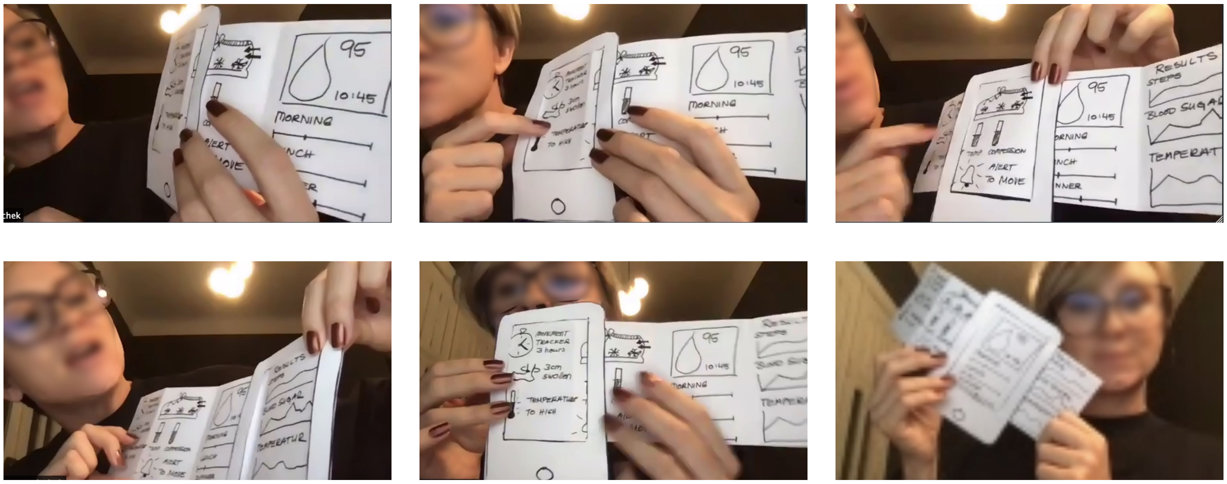
7) Analyze the post-workshop survey.

After the three-hour participatory workshop, we invited the participants to write us feedback and ideas about their experience. Only four people filled out the survey, possibly because the three-hour virtual call made our participants tired.

Even though the number of survey results was small, we valued each response and leveraged the opportunity to reach out to each participant to have a debrief session with them. One participant shared:

"Thank you very much for giving me such a chance to attend the hybrid participatory workshop. I think the three-hour workshop was well-organized in terms of time and content. Step by step. I learned the whole procedure of prototyping through the workbook. Also, it was very interesting to make a pair of slippers by hand. By connecting each paper part of the slipper together, I translated my thoughts and ideas into a real product by making. It's a very amazing experience to me."

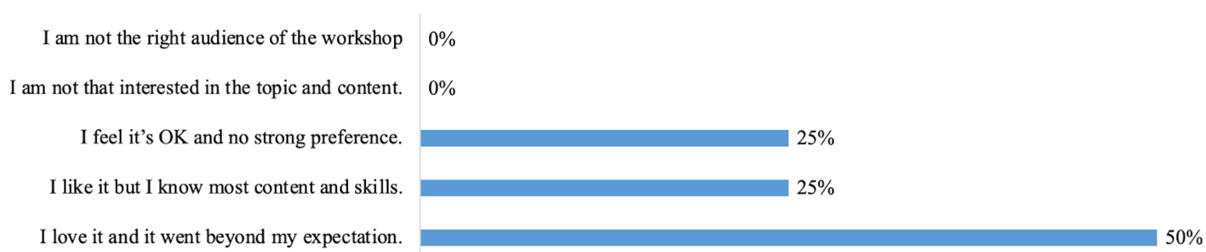
Figure 7.14. The workshop participants present their future footwear ideas and paper prototypes emphasizing on interface redesign. (photo credit: Sheng-Hung Lee)



During the debrief session, there were many great discussions and valid suggestions to help us design better hybrid participatory workshops next time. For example, one participant said that when she was assigned to one of the team Zoom breakout rooms, there were no concise prompts to help them start a conversation or tools or slides that could facilitate the team discussion to make decisions collectively.

She also shared that the workshop will work best when participants get uncomfortable at the beginning and want to go out on a limb to jump in and try answering or giving their thoughts. This allows others to feel comfortable and it moves the collective forward into better design thinking.

Figure 7.15. How do you feel about the workshop in general?
(n=4, Appendix L: survey question 3.)



Overall Hybrid Participatory Workshop Experience: The workshop participants were satisfied with the workshop experience in general (Figure 7.15.) and all of them thought the content was easy even though they didn't have any design background (Figure 7.16.). We also wanted them to write down three keywords to describe their workshop experience, such as creativity, new, and inspiring (Table 7.5.).

Figure 7.16. How difficult do you think the workshop content is?
(n=4, Appendix L: survey question 4.)

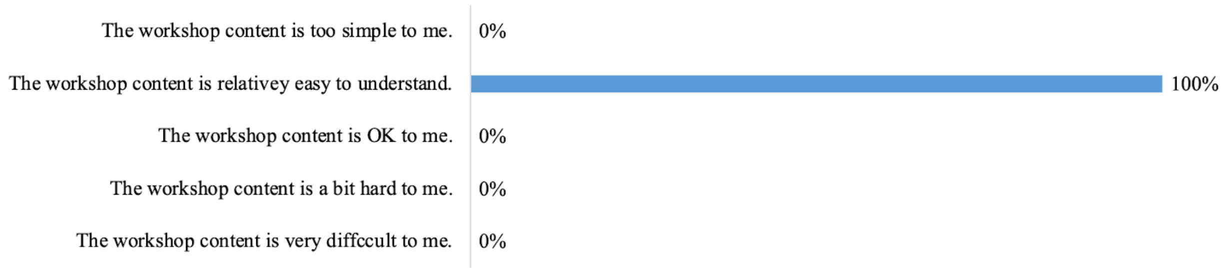
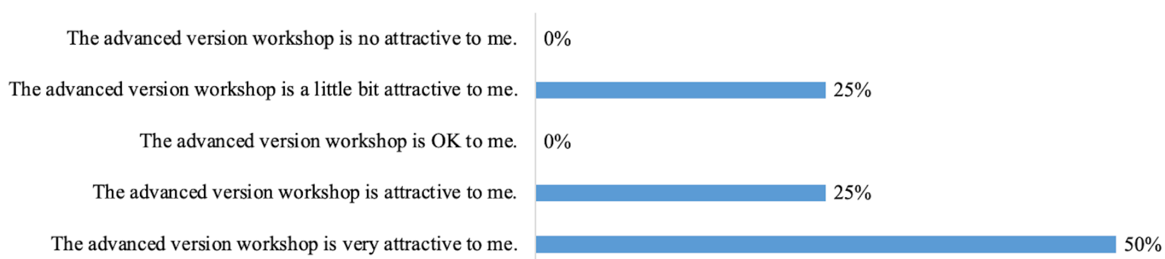


Table 7.5. Describe your workshop experience in terms of your feeling in three keywords.
(Appendix L: survey question 5.)

Participant A	**Participant B**	**Participant C**	**Participant D**
Keywords	Keywords	Keywords	Keywords
● inspiring ● broadening ● creativity	● intrigued hart to engage	● creative ● accomplished ● time well-spent	● new ● interesting ● creative

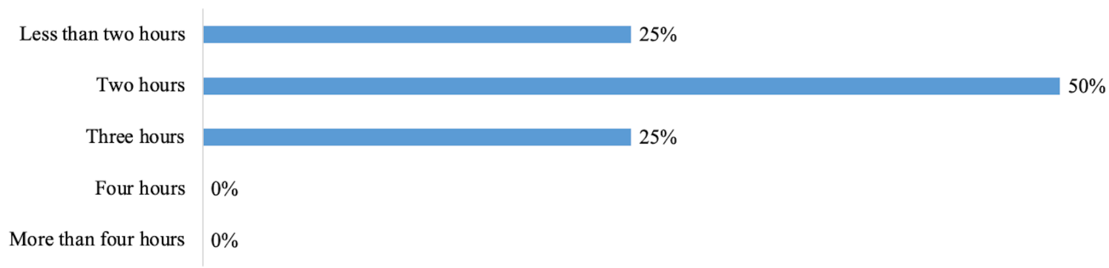
Interactive Prototyping Components: We were curious about how the participants might feel if we pushed prototype material from the paper material to electronic components, since we want to make our prototype experience more engaging during the design process. Figure 7.17. shows that most participants were excited about the advanced version, but some participants without design or engineering background were concerned that it could be a bit more difficult to follow if the workshop format were still hosted in virtual format.

Figure 7.17. If there is an advanced version of the workshop (with electronic components), how would you like to attend it? (n=4, Appendix L: survey question 6.)



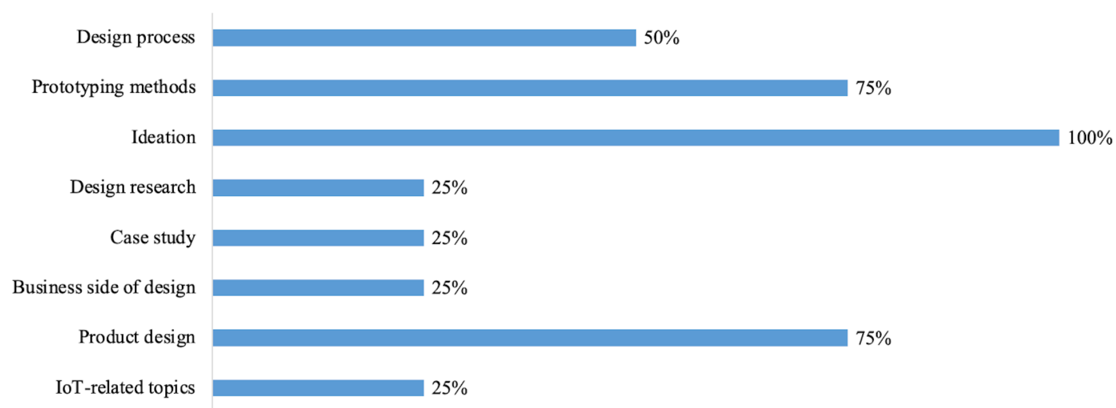
Ideal Time of Hosting Hybrid Participatory Workshop: Figure 7.18. gave us a great indication of the suitable time for hosting a hybrid participatory workshop: 50% of them thought that a two-hour workshop was the best in terms of participants' attention span, 25% thought a three-hour workshop worked better, and another 25% still preferred a workshop of less than two hours. None of them wanted to join a workshop that lasted more than four hours.

Figure 7.18. How long do you think is proper for the online workshop?
(n=4, Appendix L: survey question 7.)



Integrated Engaging Section for Hybrid Particpatory Workshop: For further workshop content development, we thought the survey results in Figure 7.19. were important to help us design and plan what we should include in the hybrid participatory workshop. In the workshop, we used footwear design as a case study. Based on the survey result, we wanted to explore other design thinking processes, e.g., ideation (100%), prototype methods (75%), and product design (75%), to have more holistic perspectives to design future footwear with our participants collectively.

Figure 7.19. Things you want to learn more from the workshop.
(n=4, Appendix L: survey question 8.)



8) Learning from the hybrid participatory workshop

Consider the hybrid participatory workshop design from toolkit, methodology to user experience: The workshop was a hybrid design collaboration experience between MIT and -ing Creatives. We define a "hybrid" workshop as one in which some participants are physically co-located while others join remotely. The term "hybrid" was defined as the transitional moment between the digital lecture/meeting and physical hands-on experience. Our co-creation toolkits include a workbook, five tutorial videos, and a website designed to integrate seamlessly to connect the online and offline design experience by applying an HCSD approach. We redefined it from inventing assistant collaboration toolkits to refining the frameworks and creative methodologies.

Design a set of interactive toolkits: The workbook design was one of the highlights of the project. The workbook was like a medium to bridge the standard online design and offline hands-on making experience to achieve real immersive and responsive team collaboration. The completed co-creation toolkit contains presentation slides, workbooks, prototyping materials, well-trained hosts, facilitators, tutorial videos, and digital channels/software.

The hybrid participatory workshop has become part of the circular process: The hybrid participatory workshop was a circular design journey—THINK, MAKE, SHARE—which consisted of four key touchpoints: 1) learning asset, 2) medium converter, 3) interactive section, and 4) community platform. The goal was to enhance the cross-disciplinary collaboration, diversify the format and interaction of hybrid learning, facilitate meaningful and efficient communication, extend the learning experience from online to offline, encapsulate the hybrid learning service into an education toolkit e.g., workbook, tutorial videos, website, and ultimately help spread social impactful ideas globally. For further steps, we will consider the circular process in-depth and make the virtual team co-creation experience more comprehensive and compact.

Figure 7.20. Group photo of all participants after a three-hour hybrid co-creation workshop (photo credit: Sheng-Hung Lee)

7.2.2. Case Study 2—Envision the Future Footwear for an Aging Population

1) Set up goals and purpose.

The topic of the four-hour participatory workshop was "Envision the future footwear for an aging population" and the purpose of this workshop was not only to make course participants learn and practice how to conduct a proper user interview with older adults, but also to gather students' ideas inspired by the conversation with the interviewees. Due to the pandemic, we did the interviews virtually and displayed the call on a big screen in the MIT Media Lab conference room. Figure 7.21. exhibited the overall flow of this hybrid participatory workshop.

Figure 7.21. The flow of the hybrid participatory workshop
(illustrated by Sheng-Hung Lee)

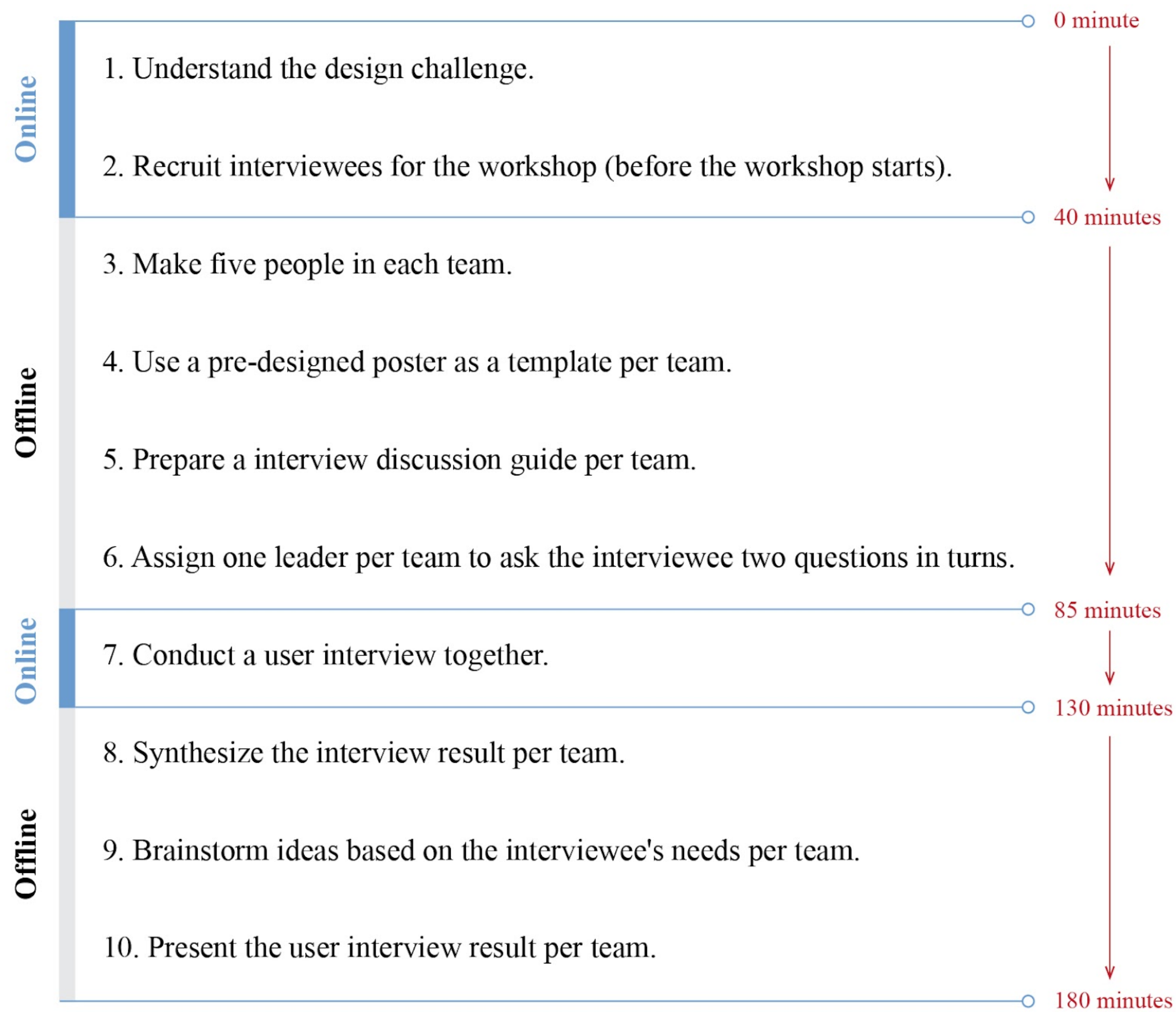


Figure 7.22. The hybrid participatory workshop opening (photo credit: Justin Knight)

2) Break into seven teams.

We started the four-hour participatory workshop by sharing the background information about indoor footwear design for older adults for an hour and then we asked 39 undergraduate and graduate students from MIT, Harvard University, Wellesley College, and Massachusetts College of Art and Design to split into seven small groups to design out the discussion guide and conduct user interview by following the instructions on the workshop poster template (Figure 7.22. and Figure 7.23.).

Each team assigned one team leader to help organize the team discussion and they took turns going on the stage to ask our interviewee two to three questions within five minutes. The rest of the team members took notes and prepared for the team's synthesized section after the whole 30-minute interview section.

Figure 7.23. The seven student groups work on their discussion guide at the hybrid participatory workshop. (photo credit: Justin Knight)

<u>3) Recruit older adult interviewees for the hybrid participatory workshop.</u>

For the interview process, we've recruited one interviewee at the age of 60, a female with a doctoral degree, with the burning need to find a pair of great footwear even though she has collected more than 50 pairs of shoes at home. She has a strong opinion on footwear design for older adults and she would spend more than $200 to purchase one pair of tailor-made shoes for herself. For her, money was not a problem. What made her worry was that she couldn't find a suitable pair of shoes on the market.

Moreover, she just recovered from hip surgery. Therefore mobility for her has become more critical than ever in her daily life. Before inviting our interviewee to the course for the participatory workshop, we had two 30-minute screenings with her to help us decide whether she was the right candidate (Figure 7.24.).

Figure 7.24. The older adult interviewee shares her footwear experience via video call.
(photo credit: Justin Knight)

<u>4) Guide with clear instructions and visuals on the posters.</u>

To successfully facilitate a workshop with guidance, we created a poster template with instructions in five sections and a 5E experience model modified from Larry Keeley's framework in 1994 [73] to help student participants learn and contribute their ideas (Figure 7.25.).

Therefore, we broke down the 5E experience model into the following five steps: 1) took notes converting three elements: people, process, and product, 2) used the 5E experience design model to capture interviewee's journey from entice, enter, engage, exit, to extend [73], 3) document the three pieces of information about our interviewee e.g., background, education, lifestyle, and ritual, 4) wrote down three quotes from our interview that participants thought were thought-provoking, and 5) drew three ideas inspired by our interview.

Figure 7.25. The hybrid participatory workshop poster design with instruction and the 5E experience design model (photo credit: Justin Knight)

5) Expect participatory workshop outcome and next step.

One major outcome of the participatory workshop was to gather students' insights and ideas on seven posters, which helped us to broaden our views on the essence of this challenge from redesigning indoor footwear for older adults to understanding the root cause of users' behavior. By the end of the workshop, we typed all the content of Post-it notes from seven posters in the Miro board to have a virtual document for further usage [146].

Figure 7.26. The hybrid participatory workshop collaborates with Dr. Hiroshi Ishii, Professor of Media Arts and Sciences at the MIT Media Lab. (photo credit: Justin Knight)

6) Synthesize interview and come up with insights and ideas.

We synthesized the seven group posters. Table 7.6. lists some quotes we heard from our interviewee, insight, and ideas (not including any visuals or drawings on Post-it notes) the participants were inspired by. Since this workshop result originated from only one older adult's interview, we cannot use this data to represent the whole age group. Instead, we want to explore some questions and early design concepts to discuss with older adults.

However, capturing key quotes and takeaways from our interviewee helped participants organize their thoughts to distill into insights. From Table 7.6., we drew four observations: 1) For our interviewee, the comfort of shoes mattered the most and was even more critical than safety. People's perceptions can be heavily based on their feelings. 2) She also did not want to have shoes that were designed for "old ladies," because this made her feel she had been categorized into the aging population already. We need to consider designing a product experience without obviously putting labels on our target users. 3) People's foot health conditions were various. Our interviewee had hip surgery recently, which influenced her walking posture, patterns, and behavior. How do we design indoor footwear to adapt to different situations? 4) As indoor footwear design is a systematic design challenge, we not only think about the features of shoes e.g., function, material, types of shoes, but also consider user experience e.g., their behavior changes, and feet skin touch experience.

Table 7.6. Interviewee's quotes and participants' early ideas (organized by Sheng-Hung Lee)

Interviewee's quote	**Participants' early ideas** (not capture participants' drawing)
● "My feet are messed up." ● "If the footwear is comfortable, you can have my money. And I would tell everybody, including my family, friends, neighbors, and colleagues." ● "I have over 200 pairs of shoes at home, but it's still hard for me to find the one that is comfortable." ● "I want something that looks nice on me while wearing shoes." ● "I don't want to have a pair of old lady's shoes in my shoe cabinet." ● "I want to have a pair of footwear that I will not slip, but I also want something that is soft on the front that covers and protects my toes." ● "I want shoes that can make me feel safe." ● "Can you make a beautiful sexy shoe comfortable for an older adult like me?" ● "I'm messed up after my hip surgery. I need the shoes to be soft but I would still like them to be nice." ● "Remember, we are all different including the tastes and comfort." ● "For shoes, I think the most important criterion to consider is comfort, but I would appreciate it if you can design something not only functional but also beautiful."	● Design a type of modular shoes: the top, insoles, and soles can be replaced depending on different situations and users' needs. ● Insoles conform to your feet instantly e.g., think about the brand Birkenstocks but with a better wearing experience. ● Design a pair of custom-fit/personalized shoes for each foot. ● Design a pair of shoes with sensors that track users' steps and activities. ● Design a non-slip attachable shoe pad insert for joint pain/injury prevention/comfort. ● Design footwear that users have the flexibility to change its style, color, material, and size depending on their health condition e.g., deformed feet, different situations e.g., formal event, party, casual family gatherings, and personal tastes. ● Design multi-purpose footwear (eg: indoor/ outdoor) that can adapt to different environments. ● Footwear with integrated three technology/product features: 1) rest reminder, 2) exercise guidance, and 3) health monitor. ● Since there is a lot of rain in this city (Boston), the design of the new shoes needs great slip resistance and waterproofness as two major product features. ● Design a good pair of shoes that not only aesthetically looks nice but also resolves feet pain. ● Design heat-sensitive shoes whose color changes with the user's feet temperature. The shoes can also check the user's heart step while they put on the shoes. In case of any emergency, the shoes can submit an SOS message to their medical team or their caregivers for help.

7.3. Summary of Hybrid Participatory Workshop

In Chapter 7's coverage of the participatory workshop, two-hybrid co-design workshops were completed in collaboration with -ing Creatives [129] and MIT MediaLab Tangible Media group (course: MAS.834 Tangible Interfaces) [127]. Workshops were held separately to engage with participants online and offline around the globe.

From this, we came up with three learning points: 1) Manage converging and diverging design processes collectively without losing perspectives; 2) Form inclusive and diverse sources as design input by conducting a participatory workshop; and 3) Leverage design opportunities by conducting a hybrid participatory workshop, which emphasizes how to make the workshop an engaging design tool in convening diverse mindsets and skill sets.

1) Manage converging and diverging design processes collectively without losing perspectives.

The goal of conducting two rounds of hybrid participatory workshops is to help us not only gather more comprehensive suggestions, but also involve our participants as part of the design process to make it inclusive, transparent, and diverse. This is a very different research approach compared to conducting traditional user interviews or surveys. A participatory workshop builds a mutual communication channel considering team dynamics, discussion flow, co-working, and co-creation sections.

Another intention for conducting a hybrid participatory workshop is managing the converging and diverging design process while collecting different insights from the groups without losing the original ideas and creative perspectives.

For example, in the second workshop collaborating with MIT Media Lab, participants wrote their brainstorming ideas on physical Post-it notes and digitalized them after the workshop on the Miro board. This hybrid transition from physical Post-it notes to digital Miro board exercise greatly facilitated the team discussion to cluster and synthesize ideas. It helped document the entire process and also enable the participants to refer back to the content and create more.

2) Form inclusive and diverse sources as design input by conducting a participatory workshop.

One benefit of hybrid participatory workshops was making the design process more transparent, inclusive, and diverse. Even though our workshop topic was to envision the future footwear for older adults, the brainstorming section was a critical component before investing in the actual indoor footwear product design. Inclusive and diverse responses helped us to have more holistic views on the target group: older adults. Older adults have diverse lifestyles, rituals, personal hobbies, health conditions, places where they live, and relationships with family members.

One great example of creating an online participatory platform is OpenIDEO. They help participants get support to make an invaluable impact on complicated societal issues, connect with suitable innovators across the globe, and train and build participants' skills by applying design thinking approaches and guiding them to access the right resources to help make rapid prototypes [147].

OpenIDEO has already created an online interactive collaboration platform to invite participants from around the globe to brainstorm solutions to some of the most difficult, complicated and systemic challenges faced by companies and governments today. Further research can explore how to create a hybrid platform with a series of toolkits and methodologies to empower participants to contribute their ideas in a democratic way.

3) Leverage the design opportunities by conducting a hybrid participatory workshop.

The pandemic has greatly transformed the way we work and live, especially in terms of conducting hybrid participatory workshops. We thought about the questions: How do we design an engaging workshop experience with both in-person and virtual participants to make them feel safe, welcome, and open-minded to contribute their ideas? How do we develop a series of toolkits or props to help us better facilitate hybrid workshops that create a positive and creative environment? How do we make collective decisions while maintaining our opinion during and after the hybrid workshop?

These reflective questions allow us to revisit the current research phase of the HCD process. There are many spaces where we can integrate the digital touch point within the design thinking process. For example, when we conducted a virtual workshop with -ing Creatives, we prepared a workbook for the participants to download and print in advance for making paper prototypes of footwear design [129].

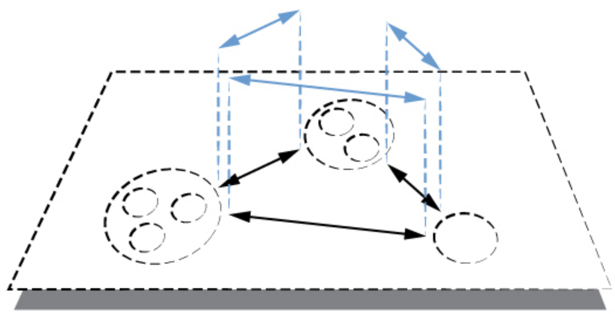
Another example was using a virtual Miro board paired with physical Post-it notes, which made the brainstorming phase more accessible for participating online and offline; it was relatively easy to share content, ideas, and feedback and keep the document organized afterwards. It is a scalable approach for brainstorming that we had not experienced before the pandemic.

Figure 7.27. Host the hybrid participatory workshop at the MIT Media Lab.
(photo credit: Justin Knight)

In the study, we designed indoor footwear for older adults with tracking trajectory functions by using Ultra-Wideband (UWB) assistive technology. To successfully leverage the benefit of the UWB assistive technology and integrate it into our footwear design, we built RTLS in advance in the project. We decomposed its building process into three steps: 1) plan the user journey, 2) prepare the device installation indoors, and 3) analyze people's indoor trajectory data.

Due to the pandemic, we didn't have a chance to install the device in older adults' homes for the sake of health and safety issues. The data we captured from the author's graduate student dorm is an example to demonstrate some early concepts of applying UWB assistive technology.

Figure 8.1. Use technologies to study the connections between each element in the system.
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



To better prepare for the indoor tracking experiment, we drew a series of storyboards to help us envision three different types of scenarios that we hypothesized when people wore indoor footwear at home (Figure 8.2.).

Since this was still at an early stage of the design process, we didn't specify people's age and persona in the storyboard in order not to limit other potential ideas during the product design and development process.

Figure 8.2. Sketch out the storyboard of the indoor footwear design and user experience.
(photo credit: Sheng-Hung Lee)

8.1. Footwear Technology Overview

We've covered critical material in literature reviews: 2.1.6. Apply Emerging Assistive Technologies to Redesign Indoor Footwear for Older Adults. In this section, we focused on the specific UWB assistive technology from Pozyx, an RTLS (Real-Time Location Systems) technology company that originated from Belgium. This study won't cover in-depth technical innovation. Instead, we emphasized more on the application of the UWB assistive technology.

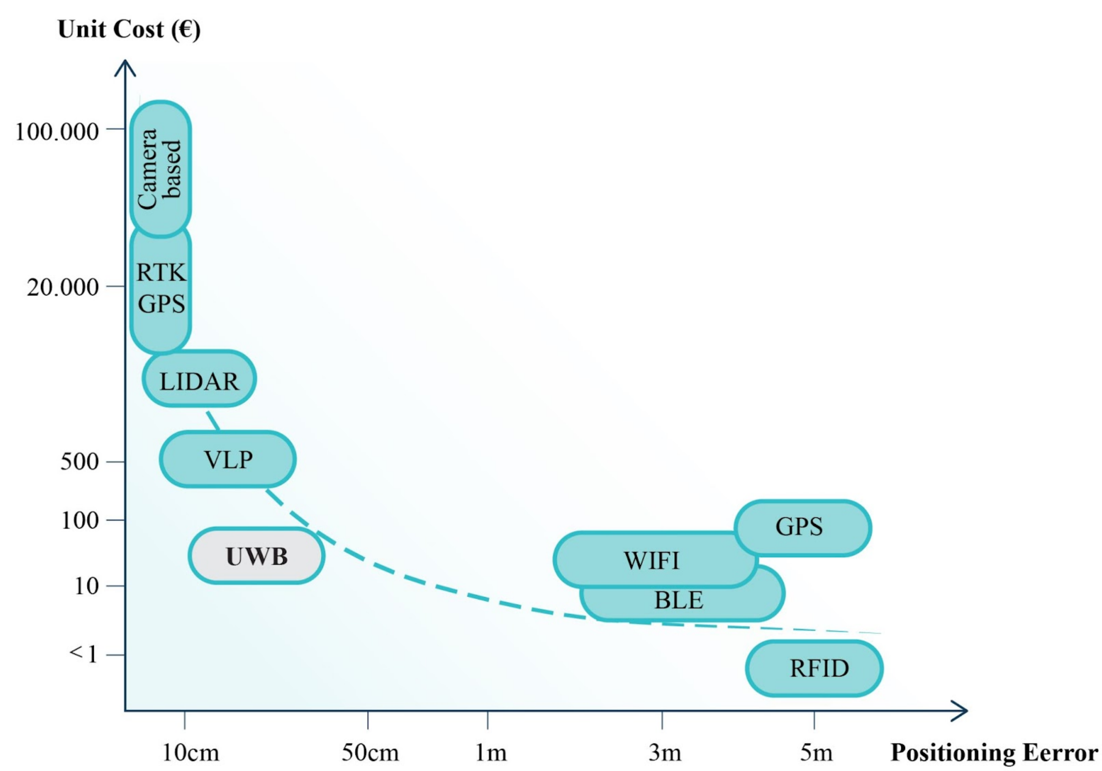
Table 8.1. and Figure 8.2. exhibited why we used Pozyx for our study. Its UWB assistive technology provides high measurement accuracy (up to 10 centimeters precise), the robustness of systems, high value per cost, reliability of position results, and scalability of experiments.

Table 8.1. The comparison on different trajectory tracking systems and technologies
(information from Pozyx website [148])

	Measurements	**Reference points**
GPS	(Pseudo-) distance	Satellites
Pozyx (Ultra-Wideband, UWB)	Distances	Anchors
Camera based	Video image	Camera (with orientation specified)
WIFI or BLE fingerprinting	Received signal strength (RSS)	The fingerprints in the database
Digital compass	Magnetic field vector	The magnetic north
Dead reckoning	Acceleration and angular velocity	Your initial position and direction

Compared with other indoor positioning technologies (Figure 8.3.), UWB showed the sweet spot located between the unit cost and positioning error to deliver the high position accuracy with relatively low cost for us. Its high immunity to interfaces is another reason why we used UWB. Its low latency mechanism helps us to receive true real-time data from our subjects e.g., target users or things. Its wearable tag design powered by low energy proves a more competitive advantage for further location position applications.

Figure 8.3. The unit cost and position error diagram of indoor positioning technologies.
(illustrated by Sheng-Hung Lee and adaptive from Pozyx diagram)



8.2. Real-Time Location Systems (RTLS)

To help us better build a RTLS, we firstly need to understand how position works in terms of basic theories and methodologies. In this secession, we covered three parts: 1) measurement, 2) reference point, and 3) trilateration [148].

1) Understand the concept and application of measurement.

When people talk about measurement, we immediately think about measuring the temperature of today's weather, the distance between two objects, the angles of a triangle, or the speed of runners. In a sense, we can measure almost anything depending on the reference points and how we define the position. Besides, we also need to consider the accuracy of the measurement and how we can avoid the error during the measurement.

2) Define suitable reference points before building RTLS.

Measurement is a relative term. When we describe measurement, the result is actually the distance/angle/number between two or multiple reference points. Defining the suitable reference point is critical before we build RTLS. It helps us know what and where we compare with and how to improve the accuracy of results from the measurement.

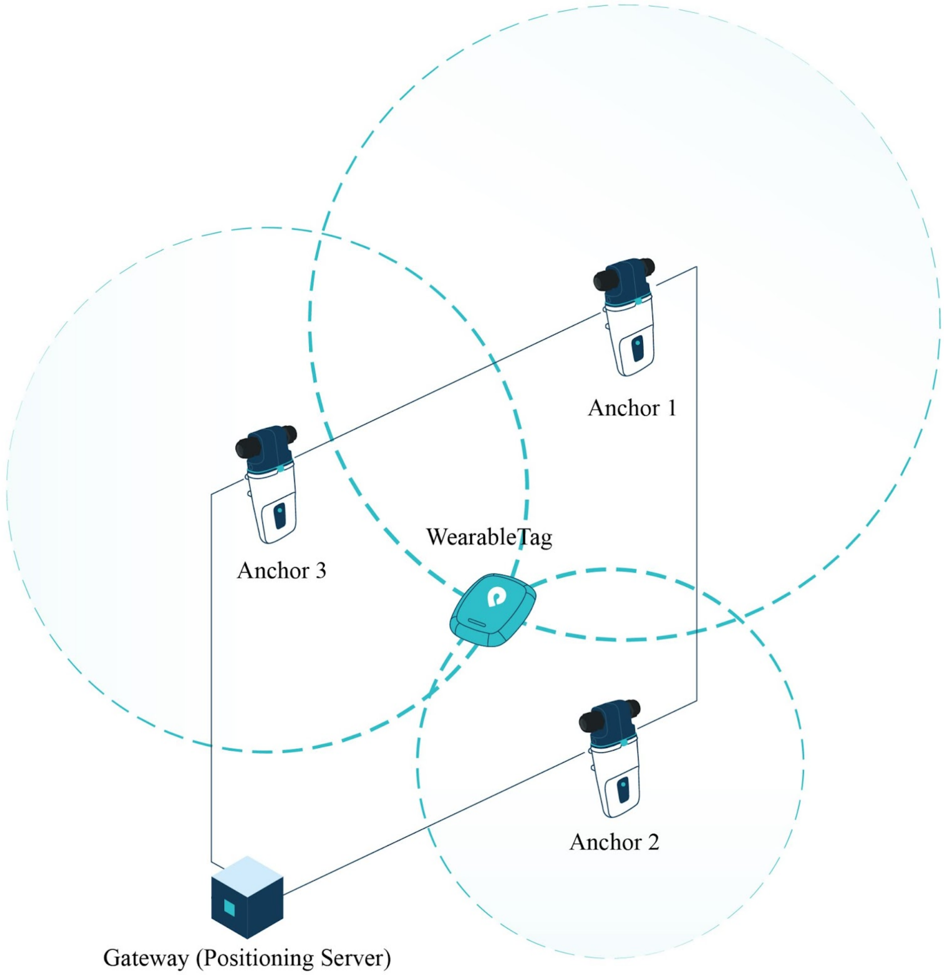
In the study, we used Pozyx Enterprise anchors as our reference points to measure the live location of subject with wearable tags. In a two-dimensional coordinate system, we can find the position by three anchors. For the three-dimensional world, we might need four anchors or even more.

3) Identify the position of subject through the trilateration approach.

When we build the RTLS system through UWB technology, we applied trilateration, one commonly used approach of positioning, to estimate the subject's position by basic geometry: the unique intersection points or area of three circles (Figure 8.4.). We can view each Enterprise anchor as one circle to emit a signal to identify the position of either wearable tag or developer tag by measuring the distance between the three anchors. We call this approach trilateration. We called it multilateration if there are more than three anchors we use in the system.

The downside of using the trilateration approach is the accuracy of measurement. The problem lies in the noise or error that originates from distance measurement between each anchor and the tag in the system, with the result of no intersection point among the three circles. To circumvent the technical issue, one optional solution is to define the measurement as starting from the point that is closest to each circle.

Figure 8.4. The concept of the trilateration approach
(illustrated by Sheng-Hung Lee and four icons designed by Pozyx)

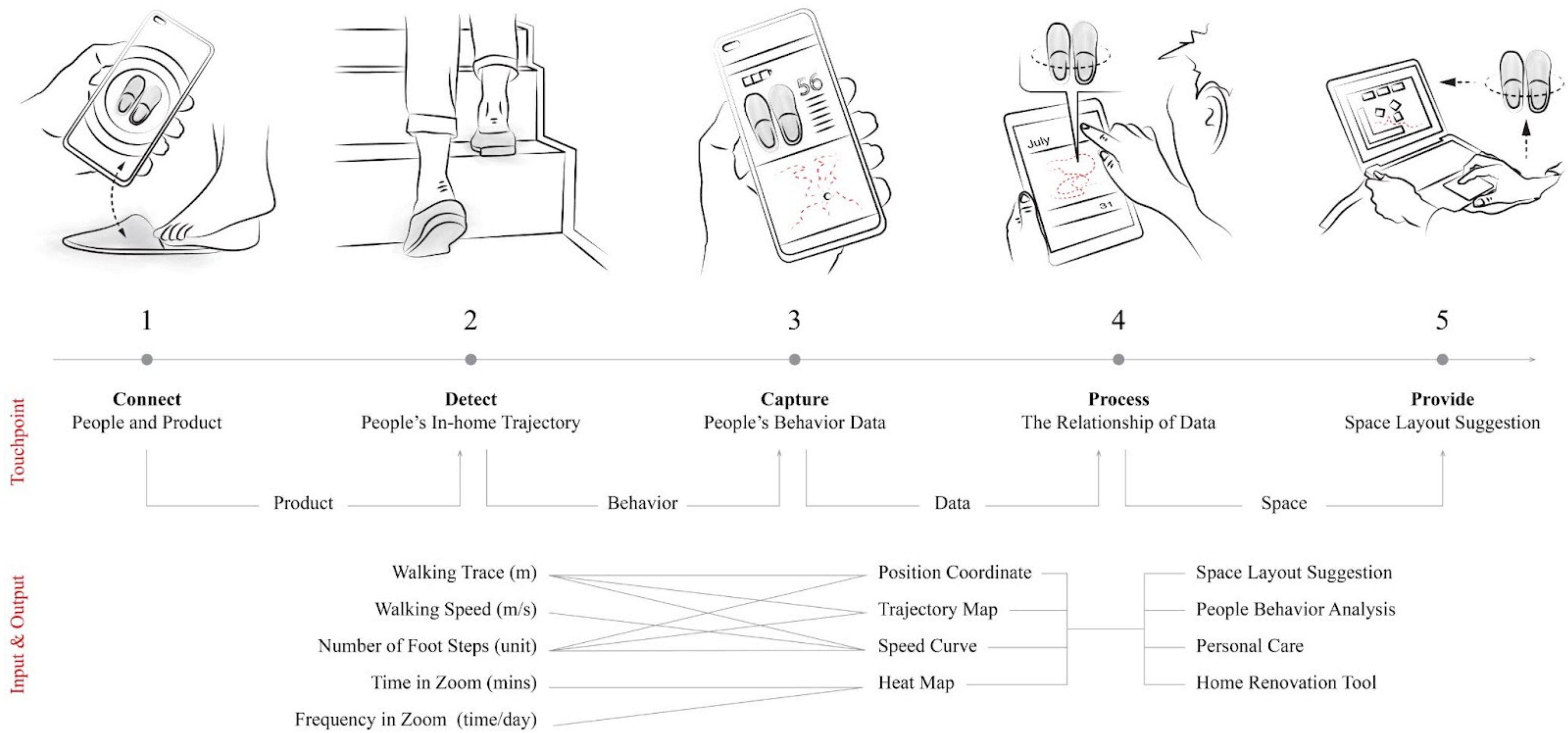


8.2.1. Plan the User Journey through Storyboarding

There are three reasons we used storyboards before experimenting with RTLS: 1) design a better user experience when people wear indoor footwear, 2) envision the experience that we want and can control, and 3) help us identify the key service touchpoint that we might be missing while we design a new type of indoor footwear.

Since this was an early stage of the design, we didn't limit our target users to older adults. Instead, we made it more generalized to help us envision the user journey and to put the indoor footwear design in the context of people's homes in three suggested scenarios. We designed not only a physical indoor footwear product, but also the service around the product to deliver a better human-centered user experience (Figure 8.5.).

Figure 8.5. Storyboard flow by using 1-2-3-4 Chart (illustrated by Sheng-Hung Lee)



In each frame of the storyboard, we followed the same structure with four criteria to design the user experience: 1) scenario title, 2) scenario description, 3) design considerations, and 4) footwear status. The four criteria were shown in detail in the following:

1) Scenario title

This is more than a title. We designed a short sentence to illustrate the key moment of the storyboard so that people can immediately "feel" the scenario in context when reading the title.

2) Scenario description

Besides using visuals to tell the story of user experience, we described stories by text including who, when, where, what, and how to each frame of the storyboard. It complemented some of the details, emotions, and behavior that visuals can't present.

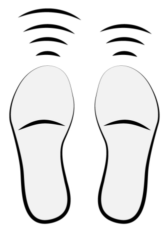
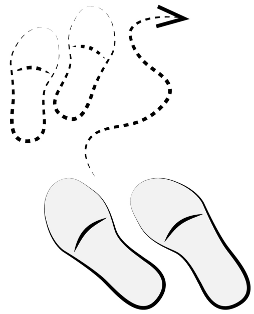
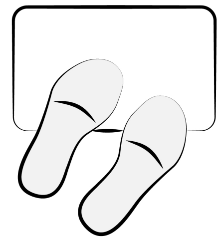
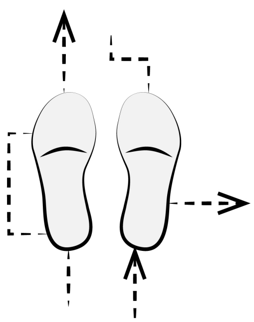
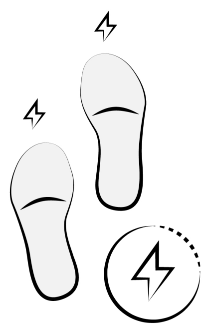
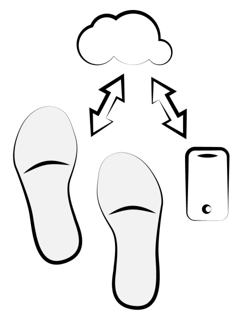
3) Design considerations

With the help of the visuals and text, it brought the stories to life, which enabled us to consider some design challenges we would be facing for the further step. Design considerations helped us pay attention beyond design perspectives.

4) Footwear status

There were six predefined statuses we used to describe the product features of footwear design, including awake, swim, freeze, wander, recharge, and transfer. Table 8.2. shows the explanation of each footwear status. We wanted to view indoor footwear as a "person" with its own characteristic e.g., how indoor footwear interacts with its users at home in various situations, how users maintain an indoor footwear product properly so that people can enjoy it better while using it.

Table 8.2. Footwear status (illustrated by Sheng-Hung Lee)

Status	**Awake**	**Swim**	**Freeze**
Icon			
Action	Activate the product The product is activated by the user's movement and the App.	Linear movement The trace shows that the user has a clear destination in mind to go to.	Static movement The trace indicates that the user stands at certain points or areas for a while.
Status	**Wander**	**Recharge**	**Transfer**
Icon			
Action	Organic movement The trace reveals that the user is exploring other possible trajectories in space.	Refill the power The product needs to be recharged for the sensors.	Transmit the data The product is transmitting the data between the smart slippers and its App.

The following 28 tables represent 28 frames of the storyboard. It was a time-based user journey in which we wanted to capture every detail of a user's behavior, how they made decisions, and who the key stakeholders were in the context.

Table 8.3. Storyboard 1 (illustrated by Sheng-Hung Lee)

Fram 1) Let’s see the gift I received from my girlfriend.

Scenario description

Today is a significant day for Tom since it is his birthday. Therefore his girlfriend prepares his birthday gift—smart slippers to him for a celebration. When Tom receives the gift, he can’t wait to open it—smart slippers that come with instructions, two sensors, tailor-made soles, multi-functional shoe box, replaceable slipper strap.

Design considerations

- What are the key elements such as sensors, soles, shoe cover, in the smart slippers shoebox?
- How to navigate the user (Tom) to download the App through packaging design?
- What’s the sequence in terms of unpacking the item?
- The user (Tom) can view everything at once and the user can also assemble it in sequence through packaging design.

Footwear status

- Awake
- Swim
- Freeze
- Wander
- Recharge
- Transfer

Scenario visual

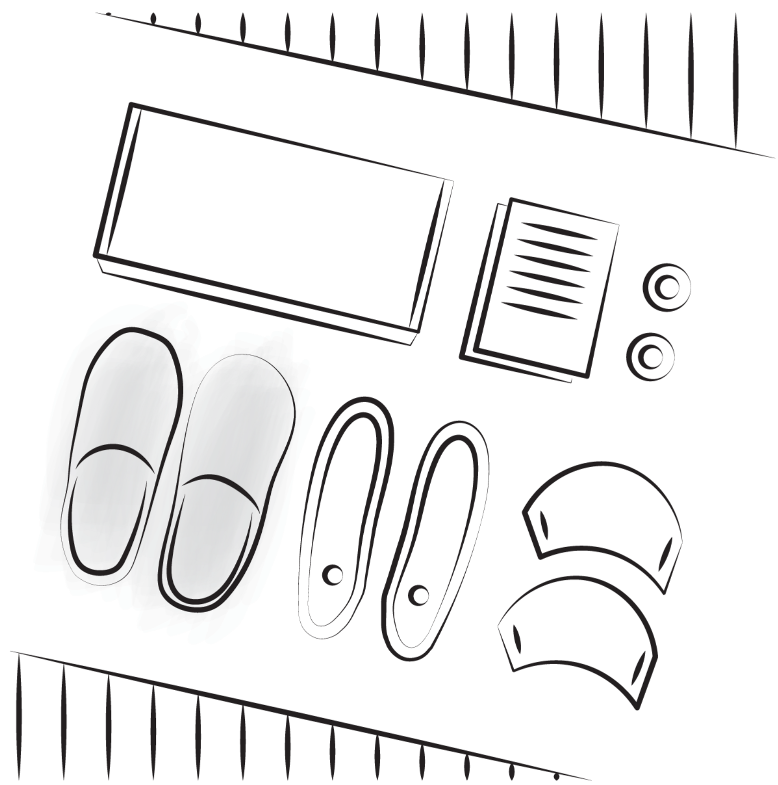


Table 8.4. Storyboard 2 (illustrated by Sheng-Hung Lee)

Fram 2) I enjoy the self-assembling experience.
Scenario description Tom needs to self-assemble the slippers by adding two sensors and its strap on each sole. It is a very intuitive assembling process and he does not even need to check the instructions. Three components: shoe body/sole, sensors, and shoe strap are designed with a clear indication of where and how to attach the join/connection of each component.
Design considerations ● How to design an intuitive product assembling experience without any instruction for the user (Tom)? ● Very obvious connection type ● How to fit/lock the component once the user (Tom) finishes assembling?

Footwear status

- Awake
- Swim
- Freeze
- Wander
- Recharge
- Transfer

Scenario visual

Table 8.5. Storyboard 3 (illustrated by Sheng-Hung Lee)

Fram 3) There is a hidden function of the package.

Scenario description

Tom also likes the extra function of the shoebox design, because he can easily transform the shoebox into a shoe rack by simply folding the dotted line printed on the box. He loves this function. It solves the problem that there is no place to put any extra shoes at his home.

Design considerations

- What are the other functions through shoebox packaging design besides product storage and display?
- What are the suitable sustainable and eco-friendly materials for the shoebox?
- Product packaging design can be viewed as a portable function or in-home decoration.
- Product packaging can be designed to deliver a message to the receiver as a gift.
- How does a product packing design fit in people's homes?

Footwear status

- Awake
- Swim
- Freeze
- Wander
- Recharge
- Transfer

Scenario visual

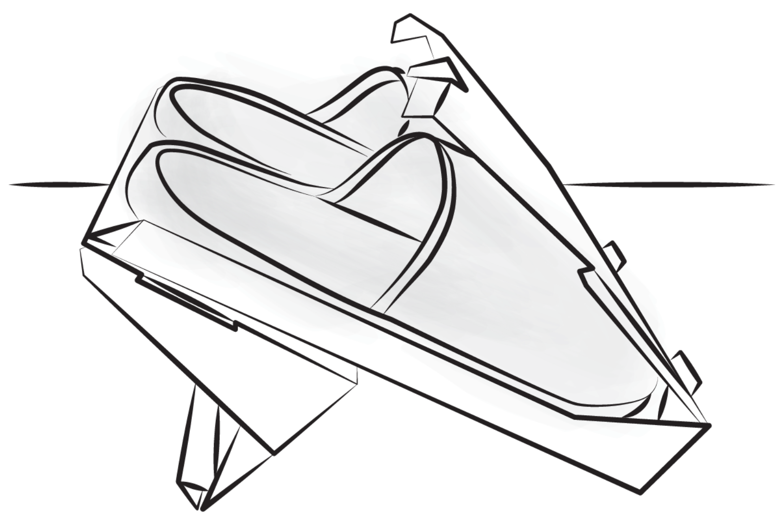


Table 8.6. Storyboard 4 (illustrated by Sheng-Hung Lee)

Fram 4) I can’t wait to interact with Sam.

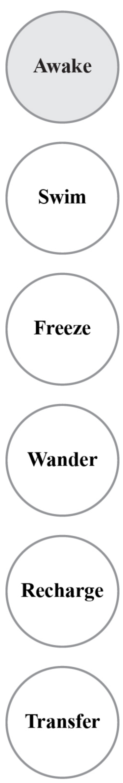
Scenario description

Tom can’t wait to put on his new smart slippers right after he assembles them. He puts them on and is ready to activate the smart slippers through the App. He loves its App design, because it is very intuitive with many visuals to guide him to finish the product initiating process seamlessly.

Design considerations

- How to design an impressive and interactive product opening experience for the user (Tom)?
- How to leverage the digital touch points e.g., App to connect the footwear project for a better customer-centric experience?
- How to design an attempting motivation to wear constantly for the user (Tom)?
- How do we repurpose the footwear box so that the brand can build a great reputation on sustainability?

Footwear status



Scenario visual

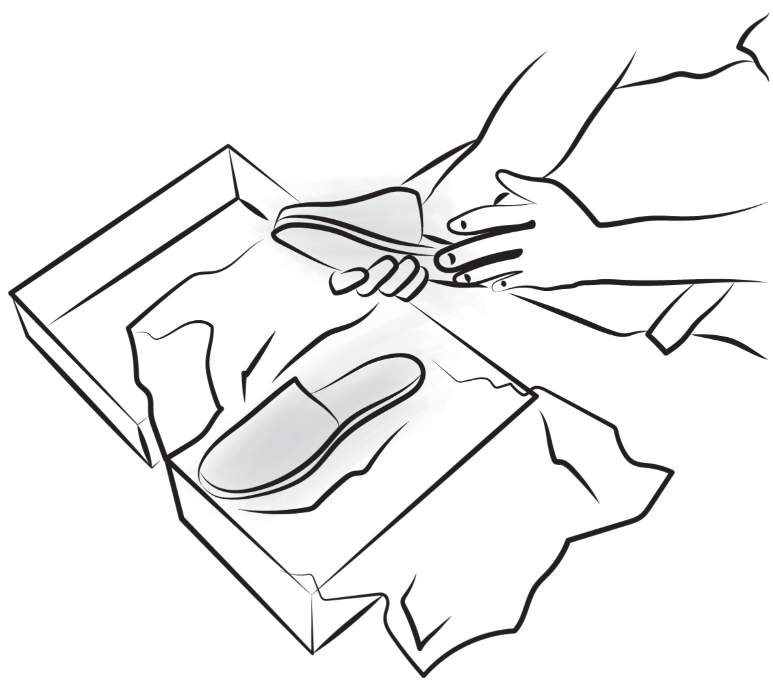


Table 8.7. Storyboard 5 (illustrated by Sheng-Hung Lee)

Fram 5) Nice to meet you, Sam!

Scenario description

Tom puts on the smart slippers and activates them through the App. Sam is a virtual assistant from the App and he is the brain of the smart slippers. For now on, Tom can communicate with his smart slippers by chatting with Sam.

Design considerations

- Product activation is critical and it is part of the packaging opening ceremony. It needs to create a positive impression by the users and enhance the overall user experience.
- It’s a critical moment to interact with the product such as when people turn on their new iPhone.
- The user (Tom) wants to make the product part of themselves. It is less about its look and exterior, but more about its content, such as the difference between purchasing Nintendo Switch and installing software in Nintendo Switch.

Footwear status

Awake

Swim

Freeze

Wander

Recharge

Transfer

Scenario visual

Table 8.8. Storyboard 6 (illustrated by Sheng-Hung Lee)

Fram 6) Please follow me, Sam.

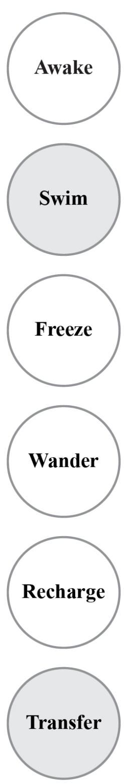
Scenario description

Tom is a freelance designer and he usually works from home. Before he goes to work, he must prepare a cup of black coffee for himself to make sure he can focus on work for a productive morning. Of course, he is super excited to put on his new smart slippers and walk around at home. Sam is always by his side.

Design considerations

- How can we design and curate the top view of the smart slippers that can deliver a better user experience in terms of visual and function? In short, what is the experience that we want to create for our users when they see the footwear from the top e.g., display some information on the top of the footwear?
- People would intuitively look down at the floor, which can be combined with the function of smartphone photographing. The behavior design and its features could be interesting for marketing campaigns.
- Design out people's natural behavior e.g., walking postures, walking pattern that connects with and interacts with the smart slippers.

Footwear status



Scenario visual

Table 8.9. Storyboard 7 (illustrated by Sheng-Hung Lee)

Fram 7) Enter into the working mode.

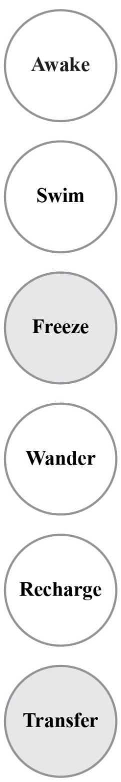
Scenario description

It is a very productive morning for Tom. He concentrates on meeting with the team and replies to clients' emails promptly after each meeting. He barely walks and sits on his office chair silently most of the time except for his biobreak.

Design considerations

- What an easy and playful way to allow the user (Tom) to find the smart slippers while he doesn't put them on.
- One of the product features that can help adjust the user (Tom)'s sitting behavior/posture while he wears them.
- It's the emotional moment that the user (Tom) will use his full feet to touch the surface of the whole slipper and to feel its texture and possible different temperatures of footwear surfaces.

Footwear status



Scenario visual

Table 8.10. Storyboard 8 (illustrated by Sheng-Hung Lee)

Fram 8) I need to stay away from Sam for a while.

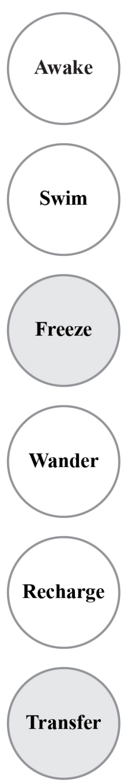
Scenario description

Tom feels a bit tired after four hours of highly productive work at home. He decides to sit on the floor and relaxes a bit and plays with his cat Molly to shift his attention. He hasn't chatted with Sam for a while during work in the morning.

Design considerations

- When is the suitable time to recharge the smart slippers while the user (Tom) doesn't put on the smart slippers? What is the convenient way for users to recharge the smart slippers e.g., wirelessly?
- The slippers can be in the sleeping mode once the user (Tom) doesn't wear them within a certain amount of time.
- The moment can be viewed as an indication to change the mode and send the notification to the user (Tom) via email or the App.

Footwear status



Scenario visual

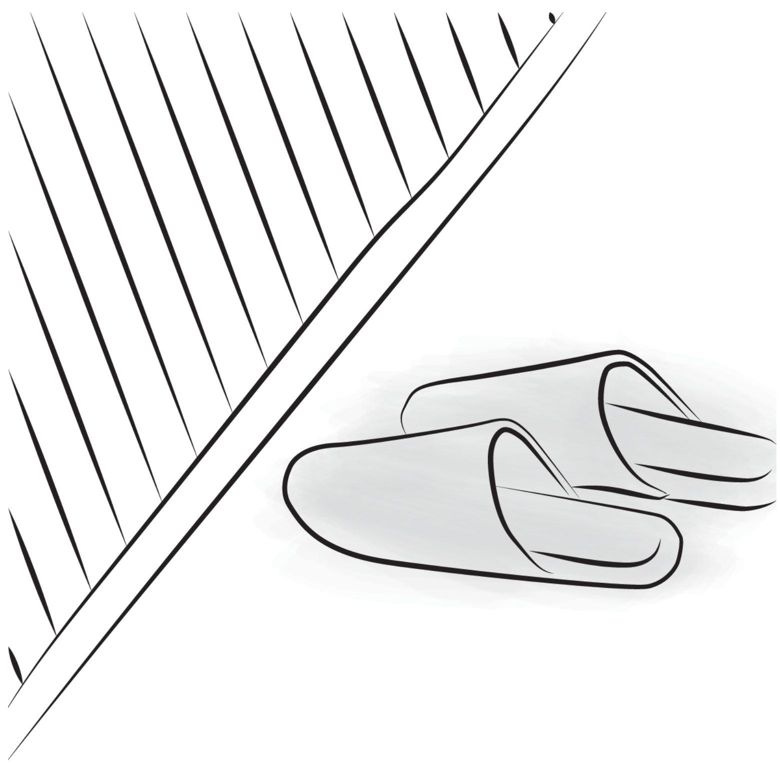


Table 8.11. Storyboard 9 (illustrated by Sheng-Hung Lee)

Fram 9) I like to play with my cat while working.

Scenario description

Molly helps Tom a lot in releasing pressure from the work mode. Tom seems very relaxed when he can move his legs around freely. He puts his document, and stationaries around him. Most importantly, he does not need to sit still all the time on the big carpet.

Design considerations

- When the user (Tom) does not put on the smart slippers, what other tasks can the App (Sam) do besides transmitting the data that can optimize the user's time?
- How do we design the sleep mode of indoor footwears?

Footwear status

Awake

Swim

Freeze

Wander

Recharge

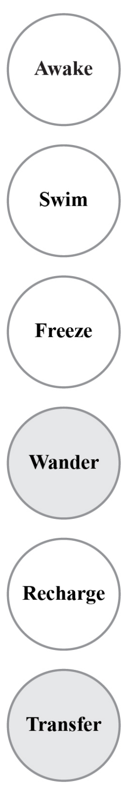
Transfer

Scenario visual

Table 8.12. Storyboard 10 (illustrated by Sheng-Hung Lee)

Fram 10) Hello again, Sam!
Scenario description After a while, Tom shortly realizes he needs to have a short break from the work to energize and refresh his mind. He “wakes” Sam up and heads to the sofa near the window while bringing his novel.
Design considerations ● When the user (Tom) steps into a new area of the room, what are the responses from the App (Sam)? And how can the smart slippers capture that location change? ● What’s the reaction when the user (Tom) walks on different textures of material or does the friction change? ● The smart slippers can provide different sensorial feedback such as subtle vibration to remind users that they are stepping on different materials.

Footwear status



Scenario visual

Table 8.13. Storyboard 11 (illustrated by Sheng-Hung Lee)

Fram 11) I need a break to refresh in the middle of the day.

Scenario description

Tom feels totally relaxed and peaceful in mind. The 30 minutes of short break only belongs to him. The sofa is put in the corner of the living room to keep an environment with semi-private space, so that Tom can sort of hide in the corner. The sunlight that spreads on his face makes him feel very cozy and warm.

Design considerations

- Can the smart slippers and its App (Sam) remind the user (Tom) to take a break after a certain amount of time at work?
- When the user (Tom) has the posture shown in the image, the smart slippers can generate or facilitate air flow.

Footwear status

Awake
Swim
Freeze
Wander
Recharge
Transfer

Scenario visual

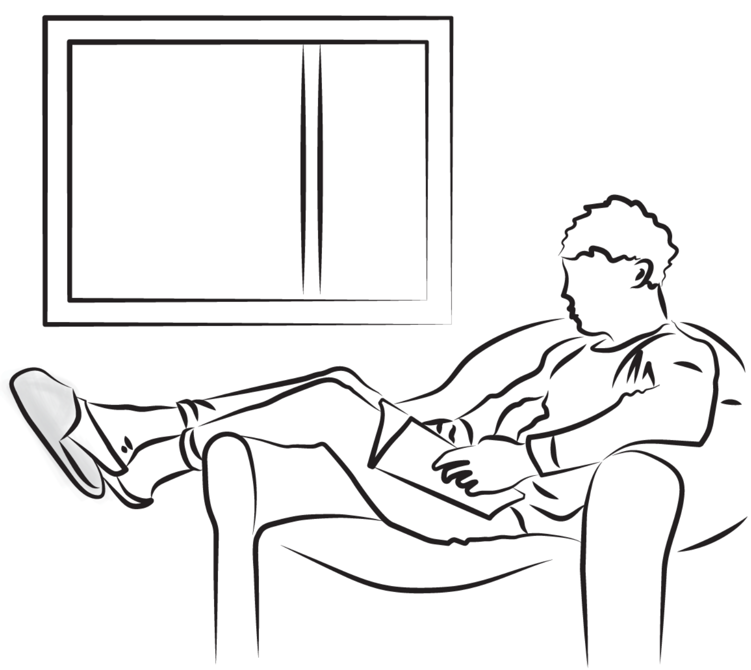


Table 8.14. Storyboard 12 (illustrated by Sheng-Hung Lee)

Fram 12) It seems like Sam wants to chat with me.

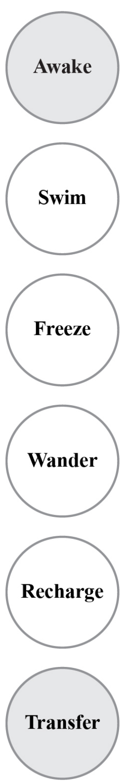
Scenario description

Tom receives a notification from Sam from App. Sam reminds him how many steps he walks this morning and the record of his in-home trajectory. He is a bit surprised at the result that he didn't move or walk a lot this morning, even though he thought he did.

Design considerations

- What are informative and user-friendly ways to present the user behavioral data through interface design?
- What type of data such as in-home trace, frequency, or time in the area matters to the user (Tom)?
- If the user (Tom) turns off the notification of the App, what are other ways to notify people?
- What and why can the user (Tom) apply for the data such as their in-home trajectory he receives? Does it mean the data is a sharable and meaningful art creating process that can trigger conversation?
- It will be interesting if the design can treat people's in-home maps as Google maps. What are the other potential applications that the user (Tom) can do?
- How to give the user (Tom) stimulus or attention through the App?
- What and why does the user (Tom) need to update the smart slippers software?

Footwear status



Scenario visual

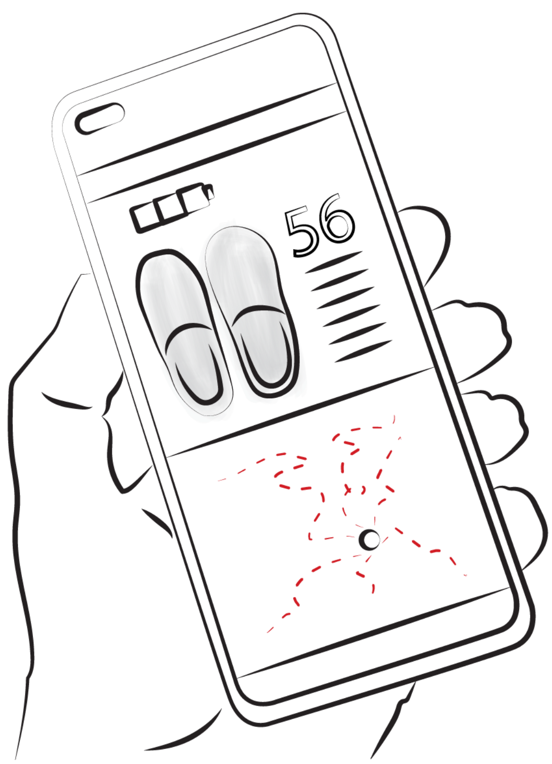


Table 8.15. Storyboard 13 (illustrated by Sheng-Hung Lee)

Fram 13) Head to the kitchen and prepare meals for his friends

Scenario description

Tom has two friends to come home tonight. After intense work for a whole day, he still decides to cook some light meal for his guests and chat with them while cooking. Sam wants to help Tom, but he doesn't know how and where to start.

Design considerations

- When the user (Tom) does a certain task such as cooking, relaxing, or chatting with friends, what are the possibilities that the smart slippers and its App (Sam) can help or facilitate?
- The user (Tom) can download different space modes/occasions such as family events, parties, and entertainment according to particular purposes, combining with his personal behavioral data.
- The product is to sell people's life stories. For example, at the Nintendo Switch product launch, three fourths of whose content was introducing the game.

Footwear status

- Awake
- Swim
- Freeze
- Wander
- Recharge
- Transfer

Scenario visual

Table 8.16. Storyboard 14 (illustrated by Sheng-Hung Lee)

Fram 14) There is an emergency email I need to reply to.

Scenario description

When Tom sends his friends back, he needs to reply to an emergency email to his clients tonight. Therefore he quickly grabs his laptop and sits on the sofa back to work mode. Sam doesn't talk to him because he knows he is in a hurry now.

Design considerations

- When the user (Tom) is under certain pressure or in the mood shifting moment, what can the smart slippers and the App (Sam) achieve such as message function, sole temperature change, color changes in order to deliver a responsive experience to meet the needs of the user (Tom)?

Footwear status

Awake
Swim
Freeze
Wander
Recharge
Transfer

Scenario visual

Table 8.17. Storyboard 15 (illustrated by Sheng-Hung Lee)

Fram 15) I walk upstairs and prepare to take a shower.

Scenario description

It is 22:30 at night. Tom feels a bit tired after he replies to the client's emails. He wants to wrap up his work for today. He goes upstairs and prepares to take a shower and relax before bed.

Design considerations

- When the user (Tom) walks upstairs or when people have vertical movement in general, what useful data can the smart slippers detect and capture to remind the user?
- When the user (Tom) has a vertical movement, the function of the fall detector can be enhanced, in case people fall off easily. We can consider this function is more critical for the older adults.

Footwear status

Awake

Swim

Freeze

Wander

Recharge

Transfer

Scenario visual

Table 8.18. Storyboard 16 (illustrated by Sheng-Hung Lee)

Fram 16) It is time for singing. Hope Sam can sing with me.

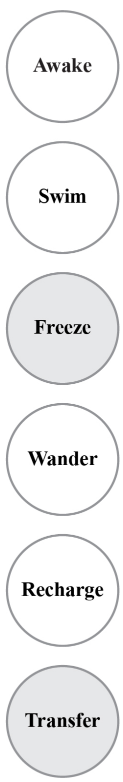
Scenario description

Tom doesn’t have a habit of taking a shower with his slippers on. Instead, he enjoys standing barefoot in the bathtub and soaks himself in the warm water, and sings freely.

Design considerations

- When the user (Tom) doesn’t put on the smart slippers, what other functions and services can App (Sam) offer to enhance the user-centered experience?
- When the user (Tom) puts on the smart slippers with wet feet, how do the different materials or textures of the sole of the slippers prevent people from falling?

Footwear status



Scenario visual

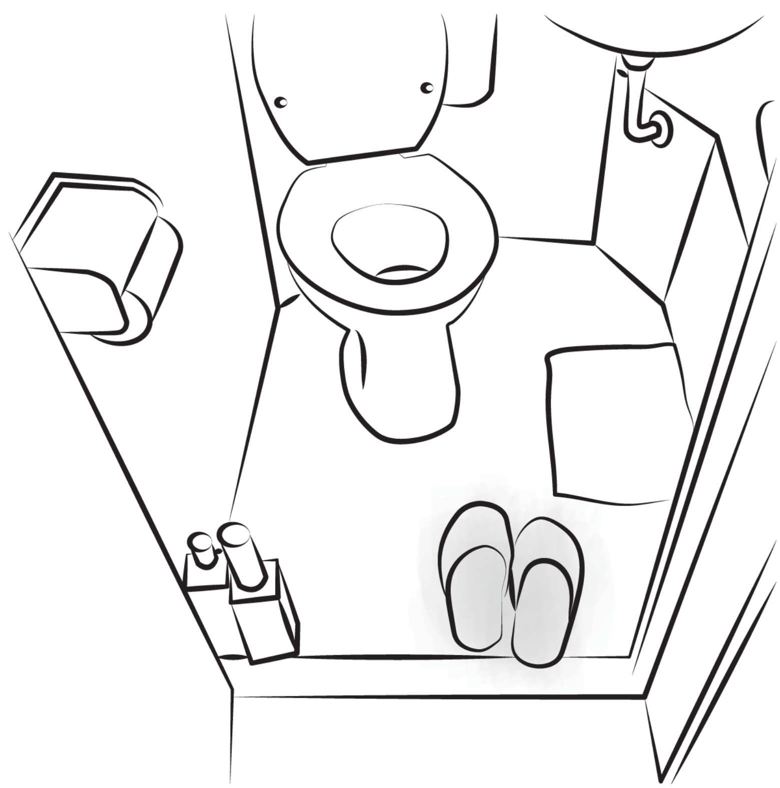


Table 8.19. Storyboard 17 (illustrated by Sheng-Hung Lee)

Fram 17) Keep my feet dry and comfortable.

Scenario description

Before Tom puts back his smart slippers, he uses the towel to dry his feet and body. Keeping his feet dry and clean makes him feel comfortable. The restroom is very foggy because the hot steam makes it difficult for the user (Tom) to find his smart slippers.

Design considerations

- What water-proof material of the smart slippers can keep the user's feet dry and comfortable?
- How to make the smart slippers easy to find when the environment is full of hot steam or lacks lights?

Footwear status

Awake

Swim

Freeze

Wander

Recharge

Transfer

Scenario visual

Table 8.20. Storyboard 18 (illustrated by Sheng-Hung Lee)

Fram 18) I jump onto the bed.

Scenario description

Tom jumps onto the bed and reads the novel for a while before going to sleep. He will leave with Sam for a while. Sam starts to process Tom's data of the day from the smart slippers. It seems like a quiet moment on the surface, but it is not. Tom and Sam are still working separately.

Design considerations

- Breathing light on the smart slippers can indicate its data transmission with the App.
- How often do the smart slippers need to transmit data to the App e.g., every time users don't wear them for an hour or set a regular time during the day for a system update?
- How to help the user (Tom) find his smart slippers if he needs to go to the restroom without turning on the light?
- What are other functions that the smart slippers can serve when the user (Tom) doesn't wear them?

Footwear status

- Awake
- Swim
- Freeze
- Wander
- Recharge
- Transfer

Scenario visual

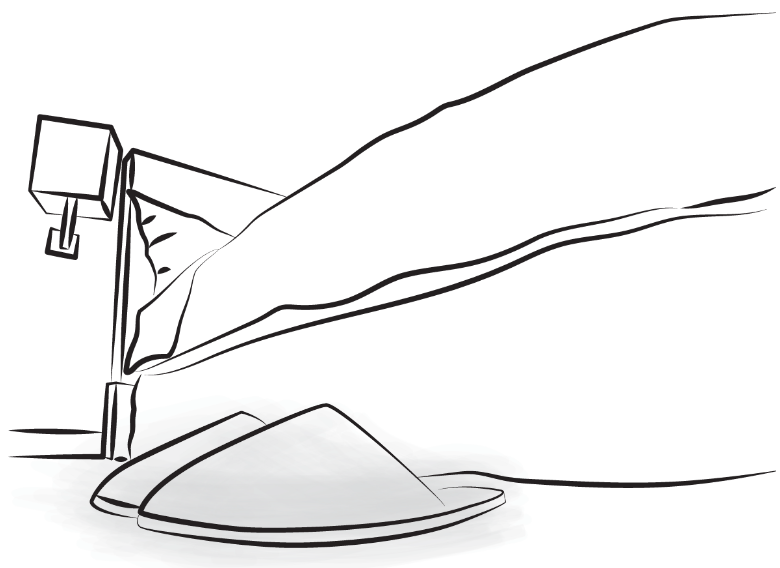


Table 8.21. Storyboard 19 (illustrated by Sheng-Hung Lee)

Fram 19) Enjoy my reading time before sleep.

Scenario description

Tom holds his warm cup of water with the novel that he starts reading this morning. He feels lucky, content, and enjoys his own personal quiet moment of the day at night. He can only see the yellowish breathing light from his smart slippers on the floor.

Design considerations

- When the user (Tom) doesn't put on the smart slippers for a while, what activities or tasks can the App (Sam) operate for the purpose of optimizing the user experience without disturbing the user (Tom)?

Footwear status

Awake

Swim

Freeze

Wander

Recharge

Transfer

Scenario visual

Table 8.22. Storyboard 20 (illustrated by Sheng-Hung Lee)

Fram 20) Sam is downloading and synthesizing the learning.

Scenario description

It is bedtime for Tom, but not Sam. Sam needs to download and synthesize Tom's behavioral data of the day.

Design considerations

- How long does it take for downloading and synthesizing data and translating it into meaningful behavioral data for the user (Tom)?
- How to inform the user (Tom) of the completion of the data uploading?

Footwear status **Scenario visual**

Awake

Swim

Freeze

Wander

Recharge

Transfer

Table 8.23. Storyboard 21 (illustrated by Sheng-Hung Lee)

Fram 21) After Sam captures the in-home tracing data for a month.

Scenario description

After a month of evaluation, Sam has more confidence to say that he has a better understanding of Tom, regarding his invisible behavior, life habits, personal interest, and some selected healthcare condition criteria. Tom also feels closer to Sam and relies on him before he makes certain types of decisions.

Design considerations

- What is a reasonable period of time such as a month or a week for the App (Sam) to conduct a full analysis before the App (Sam) can start to give the user (Tom) any suggestion?

Footwear status

- Awake
- Swim
- Freeze
- Wander
- Recharge
- Transfer

Scenario visual

Table 8.24. Storyboard 22 (illustrated by Sheng-Hung Lee)

Fram 22) Sam can suggest the best way to place the furniture.

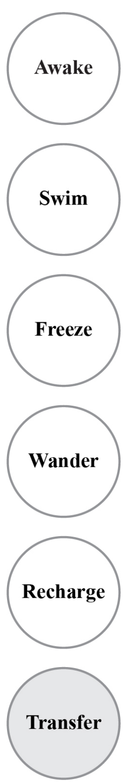
Scenario description

One of the good things about Sam is that he can make a suitable decision out of his stored library-like information of Tom's behavior, hobby, personal interest, and some selected healthcare condition data. For example, Sam will suggest where to place the furniture and plan and design the space layout depending on the specific situation to cater to Tom's needs and his behavior.

Design considerations

- Besides moving the indoor furniture, what other items such as the lighting or the direction of the route can the App (Sam) suggest to the user (Tom)?
- How to implement artificial intelligence or machine learning on the database of the smart slippers to help users make precise decisions?
- How to build a responsive interface that can implement the user's (Tom) ideas with the suggestions from the smart slippers?

Footwear status



Scenario visual

Table 8.25. Storyboard 23 (illustrated by Sheng-Hung Lee)

Fram 23) Scenario 1: When the house is only for a single person.

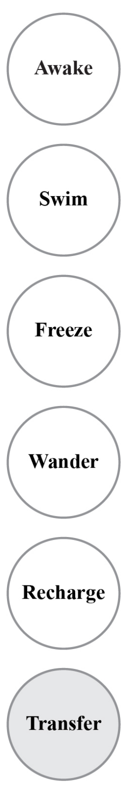
Scenario description

The first scenario is when Tom is the only person at home. Sam will give him home layout suggestions based on his behavioral data, The space should have a certain flexibility and easy for Tom to stretch his legs and body and also easy to maintain the environment because he will have different postures based on his different modes of the day such as working, relaxing, and housework.

Design considerations

- The App (Sam) can provide different types of layout based on the number of people, the purpose of the activity, the size of the space, and the vibe people want to create/curate.
- The space analysis process needs to be fun and playful.
- The relationship with the product is gradually interconnected, which is integrated into the user's (Tom) life. It leaves some room for the user (Tom) to learn and discover some new functions or features with surprise.
- The product needs to create a strong sense of dependency.

Footwear status



Scenario visual

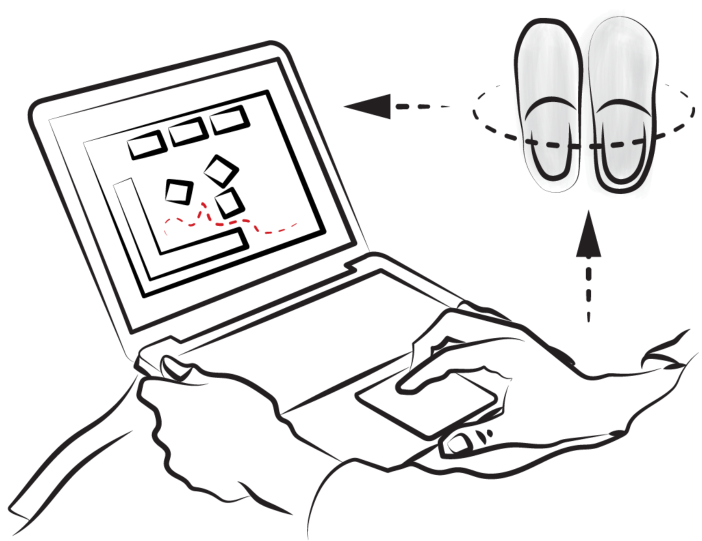


Table 8.26. Storyboard 24 (illustrated by Sheng-Hung Lee)

Fram 24) Scenario 1: When the house is only for a single person.

Scenario description

From the current space layout, Tom is in the mode of relaxing by himself. He watches YouTube on his iPad. The modular blocks can greatly assist him in stretching his back and legs while relaxing, which also differentiates the needs in the working mode.

Design considerations

- How does the App (Sam) get the feedback from the user (Tom) once he takes the suggestion from the App?
- How do we train App (Sam) through its user's request and also by implementing machine learning and artificial intelligence?
- What are the other functions that the App (Sam) can do to help the user (Tom) enjoy himself while he is in relaxation mode without affecting the user's safety?

Footwear status

Awake

Swim

Freeze

Wander

Recharge

Transfer

Scenario visual

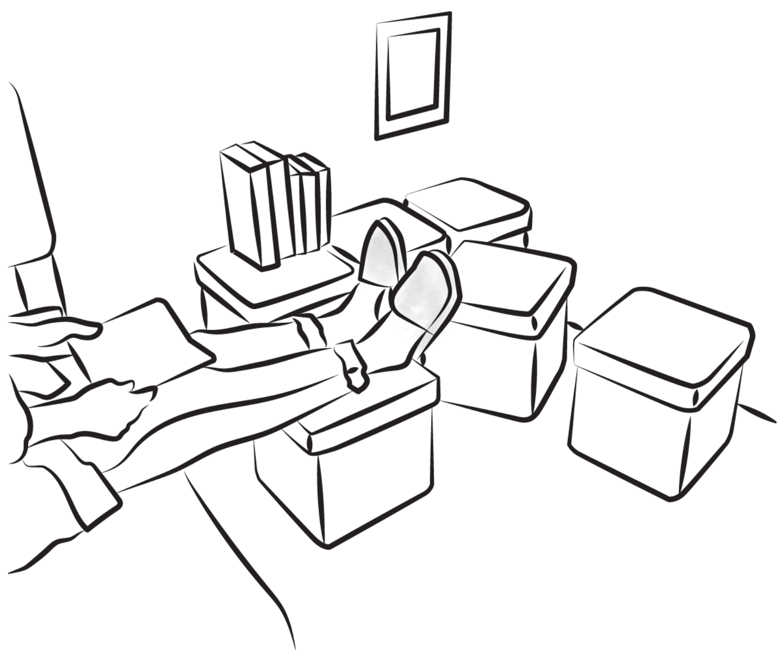


Table 8.27. Storyboard 25 (illustrated by Sheng-Hung Lee)

Fram 25) Scenario 2: When living with two family members.

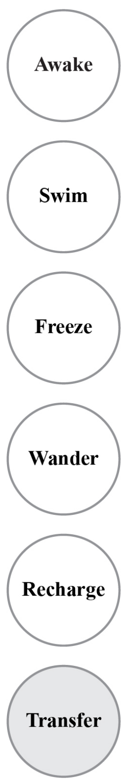
Scenario description

Tom is thinking about this summer when two of his cousins will stay with him for two weeks. He asks Sam whether he has any ideas about the reconfiguration of the home layout if there are two more people at home. Sam connects to his data library and searches for a similar situation online to give Tom a high-level suggestion merging Tom's behavior in-home data.

Design considerations

- The App could contain a shareable function by connecting with other users' behavioral data to get more comprehensive information before making any decision.
- The design experience in general is similar to playing Pokemon, which triggers people to walk outside the home, explore the city space, and stimulate the city space. Apply the spirit to the smart slippers. It is more like helping people find delight in home and exploring joyfulness at home.

Footwear status



Scenario visual

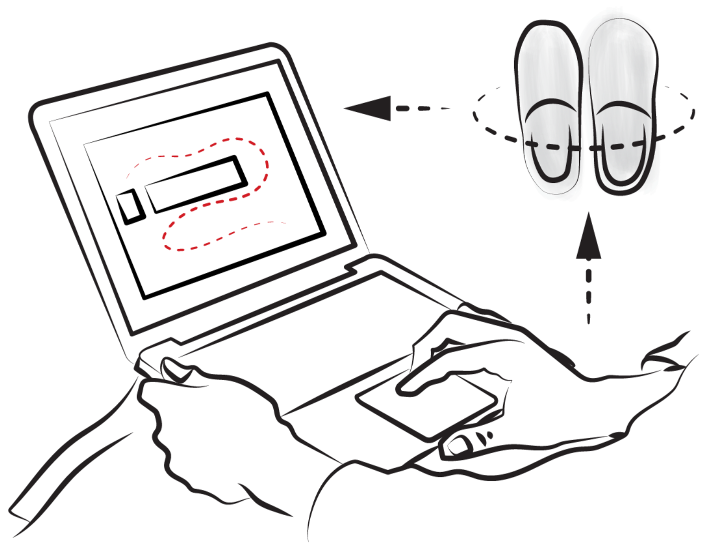
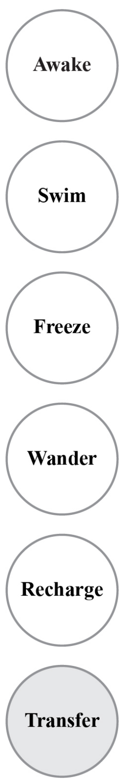


Table 8.28. Storyboard 26 (illustrated by Sheng-Hung Lee)

Fram 26) Scenario 2: When living with two family members.
Scenario description Tom takes advice from the App (Sam) and places the sofa on the side to leave more space for family members in the living room in order to create a more open and shareable room. Sam searches the information in his database to suggest adding some plants to create a cozier and more relaxed vibe for people.
Design considerations ● How to better curate the space and create a suitable atmosphere by placing the furniture and life items? ● How can the App (Sam) capture the feedback from the new space setup?

Footwear status



Scenario visual

Table 8.29. Storyboard 27 (illustrated by Sheng-Hung Lee)

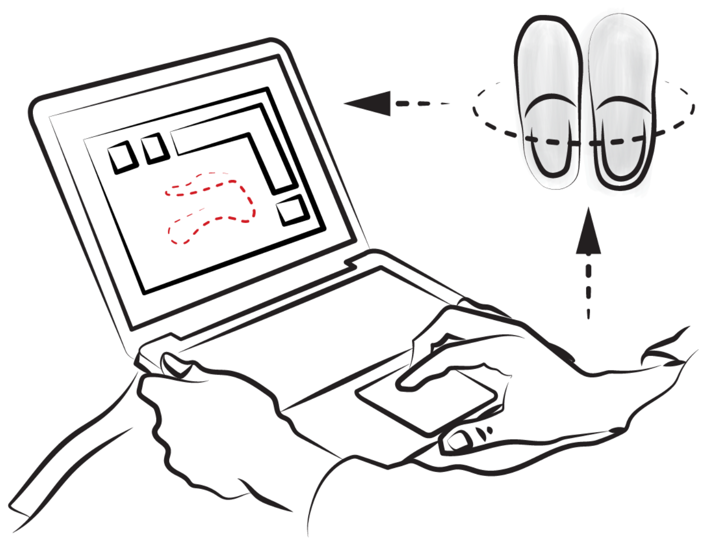
Fram 27) Scenario 3: When friends come for a party at night.	
Scenario description One Friday night, Tom invites his colleagues home to celebrate the successful final project presentation. There are more than ten people that come to his home. He also wants to ask Sam to figure out the best way to reconfigure his place and rearrange his items. Sam provides him with some similar reference space solutions online and also gives him an environmental simulation according to his home layout and the constraints e.g., number of furniture, time cost. In the end, they both decide to leave a large empty area in the center for group activities.	
Design considerations ● What judging criteria or standards allow the App (Sam) to make any critical decision or relevant suggestion to the user (Tom)? ● How does the App (Sam) receive the user (Tom's) feedback and provide ideas that can adapt to the real situations?	
Footwear status	**Scenario visual**
Awake Swim Freeze Wander Recharge **Transfer**	

Table 8.30. Storyboard 28 (illustrated by Sheng-Hung Lee)

Fram 28) Scenario 3: When friends come for a party at night.

Scenario description

Tom and his friends had a great time together. Tom appreciates Sam’s constant help and the great tips he provided. He would love to recommend the smart slippers and Sam to his friends and family, because Tom feels he is empowered and it is very convenient for him to have a caring personal assistant that wants to live with him, to chat with him, and to understand him as if Sam were his family member.

Design considerations

- When there is more than one pair of smart slippers at home, how does each pair of smart slippers communicate and connect through the App (Sam)?
- How do users build trust between smart footwear or other IoT devices and themselves?
- What is people’s comfort level of data privacy if people know their behavior data e.g., their indoor trajectories are captured and stored in the cloud?

Footwear status

Awake

Swim

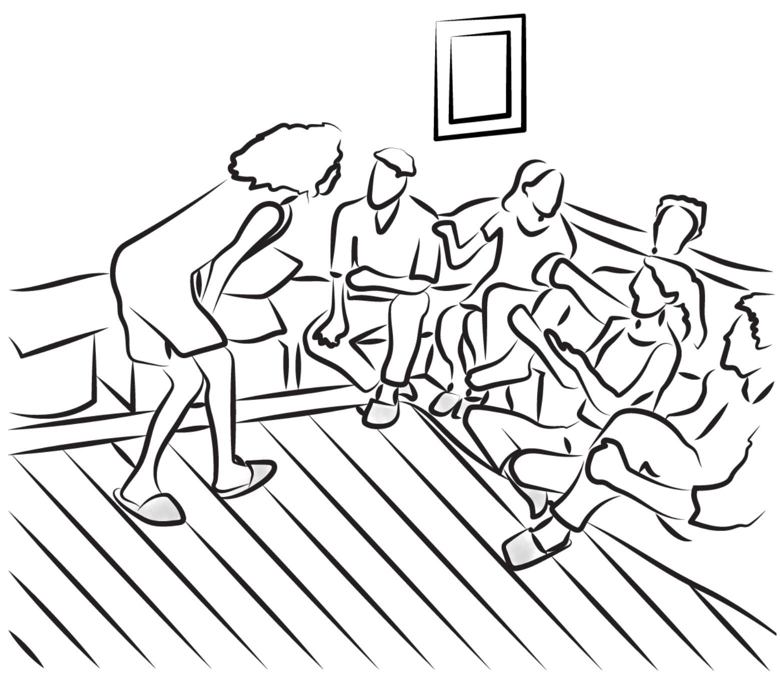
Freeze

Wander

Recharge

Transfer

Scenario visual



8.2.2. Prepare to Install the Tracking Device Indoors

We planned to prototype older adults' indoor tracking at their homes to gather first-hand material for analysis. Due to the pandemic and safety concerns, the moment to conduct the experiment was to use the place the author lived as the most feasible option. The author used the 10-day self-quarantine opportunity to conduct the experiment without going out (Figure 8.6.). The graduate student dorm was prepared and delivered three meals and water per day.

Figure 8.6. The graduate student dorm used as the space for prototyping
(photo credit: Sheng-Hung Lee)

This experiment was conducted in extreme conditions e.g., as the subject couldn't leave the place for ten days. Our intention was to apply this assistive technology (RTLS) to help designers understand people's behavior in a scientific approach to see if there is any future opportunity to improve the quality of lives for older adults. We revealed the detailed experiment information in Table 8.31. as a reference.

We also published this part of the research and design finding—Revisiting My Self-Quarantine Experience through a Data-driven Approach at Design Management Institute (DMI): Review, a DMI journal that gathers articles and case studies around design, design strategies, methodologies, and tool, in 2021 [82].

Table 8.31. The information on the indoor trajectory tracking experiment

Address of place	Room 629, Building NW86, 70 Pacific Street, Cambridge, MA 02139, USA
Description of place	Private apartment for one occupant with a bathroom and kitchen, and all bedrooms have wall-to-wall carpeting. The unit is furnished with: ● 1 x extra-long twin bed and mattress (linens not provided) ● 1 x 5-drawer dresser ● 1 x 2-drawer dresser ● 1 x wardrobe ● 1 x bookcase ● 1 x desk ● 1 x desk chair ● 1 x side chair ● 1 x refrigerator ● 1 x stove
Area of place	320 sf
Time	10 days (use the author's self-quarantine time to conduct prototype)
Number of participants	1
Number of sensors	6 Enterprise anchors, 1 wearable tag, and 1 Gateway
Analyzed tools	Pozyx enterprise kit with its software (version of the year 2020)

Before we started to install the devices in the room, Table 8.32. displayed all the components we used for the experiment by explaining each item's name, number, purpose, spec, and icon. Most experimental components were purchased from the Pozyx enterprise kit in 2020 (Figure 8.7. And Figure 8.8.), except the six self-designed 3D-printed mounting brackets for Enterprise anchors. The kit included six Enterprise anchors with metal mounting brackets, one Gateway (industrial positioning server), two developer tags, and two wearable tags. We used the kit to test the accurate positioning of UWB to fully experience the RTLS solution.

Figure 8.7. All Pozyx enterprise kit shipped from Belgium (photo credit: Sheng-Hung Lee)

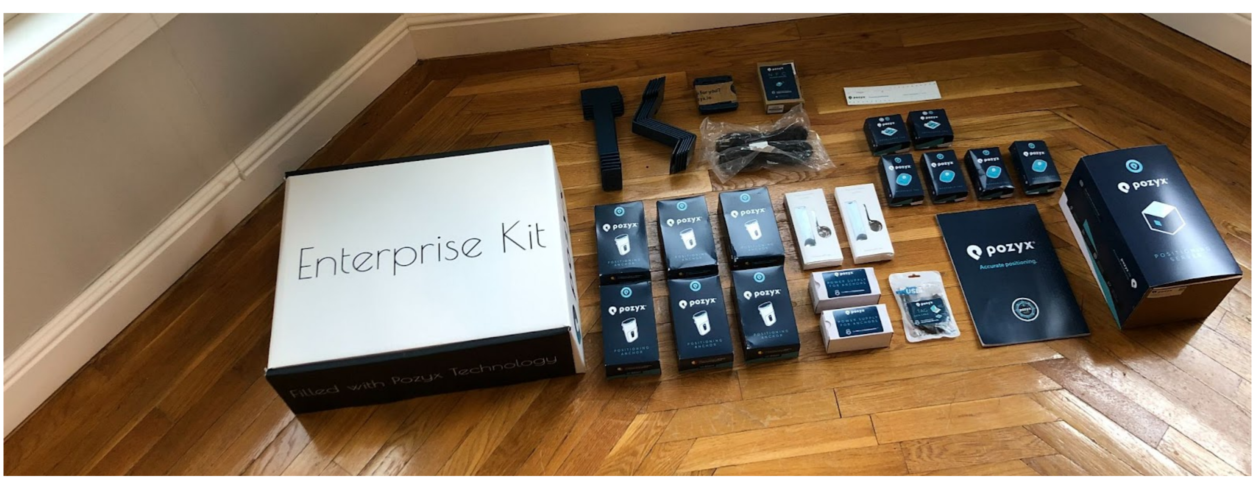


Figure 8.8. All components of the Pozyx enterprise kit and the number in each green circle stands for the device unit in the kit (image from Pozyx software instruction book)

Table 8.32. Components for indoor tracking system
(photos from Pozyx software instruction book)

Item	#	Purpose	Product spec / features (provided by Pozyx)	Icon
Enterprise anchors	6	The Enterprise anchor serves as a receiver to capture and process the signals from developer tags or wearable tags and transmit the data to the Gateway (the industrial positioning server). The kit contains six Enterprise anchors, but the system can support daisy chaining extending up to eight anchors.	● Dimensions: L158 x W98 x H53 mm ● Weight: 170 g ● Max refresh rate: 10 Hz ● Accelerometer: 3-Axis 2 g 10 bits (1.6 to 25 Hz) ● Quasi omni-directional ultra-wideband receiver ● Ultra-wideband range extension ● Processes up to 4,000 ultra-wideband frames per second	

			● Support for both TWR and TDOA positioning ● Powered by Power-over-Ethernet (PoE+) or local AC/DC convertor ● Industrial grade with IP20 or weatherproof IP66/IP67 enclosure options ● Firmware upgradable over Ethernet ● Backup firmware recovery ● SNMP support for device diagnostics	
Mounting brackets for anchors	6	Two types of mounting brackets (L-shaped ceiling mounting and multifunctional plate) for Enterprise anchors. It helps install Enterprise anchors in the experiment space.	● L-shaped for ceiling mounting ● Multifunctional plate ● Dimensions: 75 x 75 mm for multifunctional plate	
3D-printed mounting brackets for anchors	6	Self-designed 3D printed mounting brackets for Enterprise anchors. According to Pozyx's engineer's suggestion and their experience, the difference between the mounting bracket that Pozyx provides is that a 3D-printed one we designed can effectively provide Enterprise anchors with an extra wall space of 6 cm for better signal receiving and transmitting results indoors.	● Dimensions: L74 x W45 x H2.5 mm ● Material: It is printed out of PLA filament by Xometry.	
Gateway	1	The Gateway is the center of RTLS to process the data from Enterprise anchors and tags. Its web app service provides real-time data analysis and simulation based on UWB. We can modify, plan, and configure the RTLS through this web app.	● Mechanical ○ Dimensions: W210 x D125 x H77 ○ Weight: 1.9 kg ○ Mounting: VESA Mount ● Power ○ DC Input: +9~36V ○ AC Input: External adapter 100/240V; AC-DC 84W ● Environment ○ Storage Temperature: -20°C to +70°C ● Power: CE/FCC class A ● Positions: 1000 updates per second ● CPU: i5 ● Memory: 1 x DDR4 SODIMM socket, Max. 4GB ● Storage: SSD ● I/O Ports: ○ 1 x Uplink Port ○ 4 x Anhor Network Ports ○ 2 x USB 3.0 ○ 1 x HDMI	

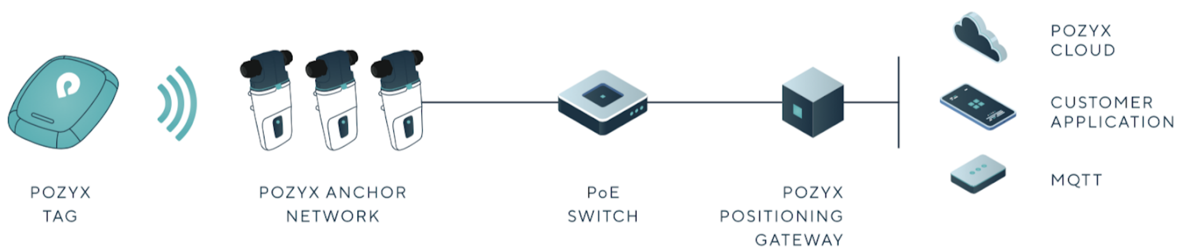
			● Optional Modules and Accessory: 3G Antenna	
Web app	1	The Pozyx enterprise kit provides a user-friendly web app as an information hub to help researchers or designers get data access in real-time, plan where to put anchors, optimize the product (anchor and tag) deployment process easily, conform each step of installation, run performance maintenance program, map out the location of every tag and anchor in bird's-eye view for easy management.	● Provide a user-friendly management system. ● Have a holistic view of each anchor and tag to make the deployment process easy by having a predicted performance. ● Make a customized configuration system according to the target space. ● Track anchor information and simulate a network topology. ● Define experimented zones of the target space in terms of area and boundary. ● Map user's tailor-made floor plan with the support of web app in-built visualization tools ● Get access to the test subject's real-time indoor trajectory data. ● Help users validate the step during the installation process.	
Analytics app	1	The analytics app helps researchers and designers analyze data from the web app through heatmaps of indoor trajectory, spaghetti charts, zone analytics, and time spent per different zones. This app can assist researchers and designers to translate the raw materials into insight by a data-driven approach. Besides, its analytics HTTP API can be used to integrate other data into multiple systems or platforms easily.	● Heatmap: It's a great data visualization tool to help researchers or designers understand the flow of indoor trajectory of people or things to identify the bottlenecks and suggest better layout of floor plan. ● Spaghetti chart: It's a great data visualization tool to track and trace people's movement in real-time and document it. ● Zone analysis: Researchers or designers can define discreet zones in the space to specifically track the movement of people or things. ● Time budget: It can calculate time spent per different zones defined by researchers or designers or the frequency of entering and leaving different zones.	
Developer tag	2	The developer tag provides room for makers to customize their indoor positioning tag (10 cm accurate) with real-time motion information (9-axis inertial measurement unit). Makers can find its open-source libraries on Github. Its pin is compatible with Arduino Uno and also has 4 user-configurable GPIO pins.	● Dimensions: 6 x 5.3 cm ● Weight: 12 g ● Frequency range: 3.5 - 6.5 GHz ● Bitrate: Up to 6.8 Mbps ● Sensors: Motion sensor (3-axis accelerometer, 3-axis gyroscope, 3-axis compass) and pressure sensor ● Input voltage: 4.5V to 12V (DC jack) or 5.0V (USB Powered)	

Wearable tag	2	The wearable tag is a portable tag powered by a standard 3V CR2450 battery. Users can wear it on their wrists, or use it as a keychain or lanyard, or clip-on for people's jackets or hard hats for accurate indoor positioning (typically from 10 to 30 cm).	● Dimensions: 50 x 42 x 15 mm ● Weight: 21 g ● Max refresh rate: 10 Hz ● Accelerometer: 3-Axis 2 g 10 bits (1.6 to 25 Hz)	

After we learned and received all the Pozyx components we need for the experiment and understood each component's relationships within the bigger Pozyx eco-system (Figure 8.9.), we started to plan the live prototyping experiment by breaking it down into five steps: 1) room preparation, 2) device installation, 3) software learning, 4) space prototyping, and 5) result analysis. Each step was explained in the following text with photos of prototyping.

Figure 8.9. Pozyx eco-system map

(image from Pozyx software instruction book)



<u>*1) Prepare the room to set up an experiment condition.*</u>

We made a measurement of space and CADed in the software (Figure 8.10.) and also drew the floorplan to upload in the software to set up the simulation environment with the right boundary (Figure 8.11.). This is a critical step to help us get the information on the dimension of the space to place our six Enterprise anchors.

Figure 8.10. Space measurement and CADing model (illustrated by Sheng-Hung Lee)

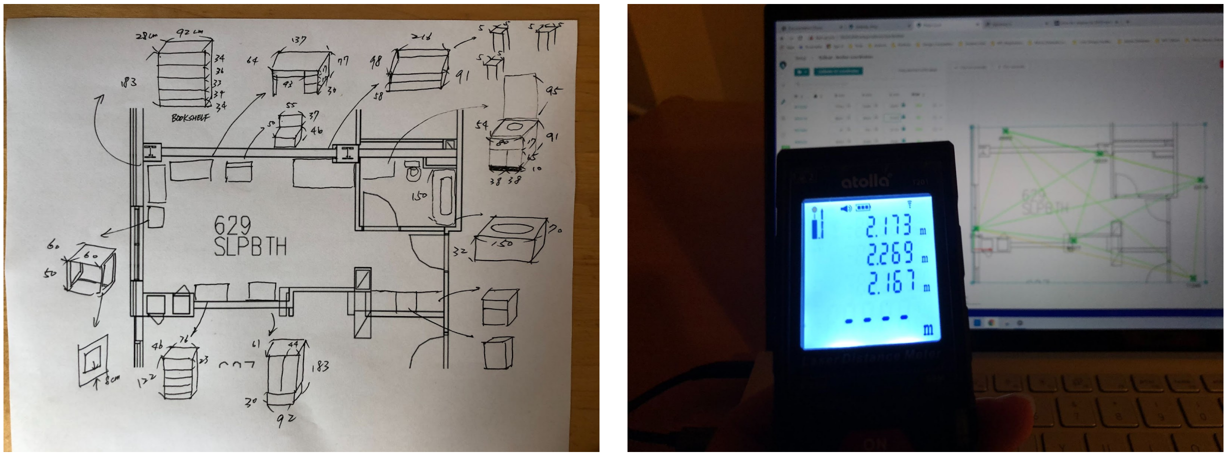
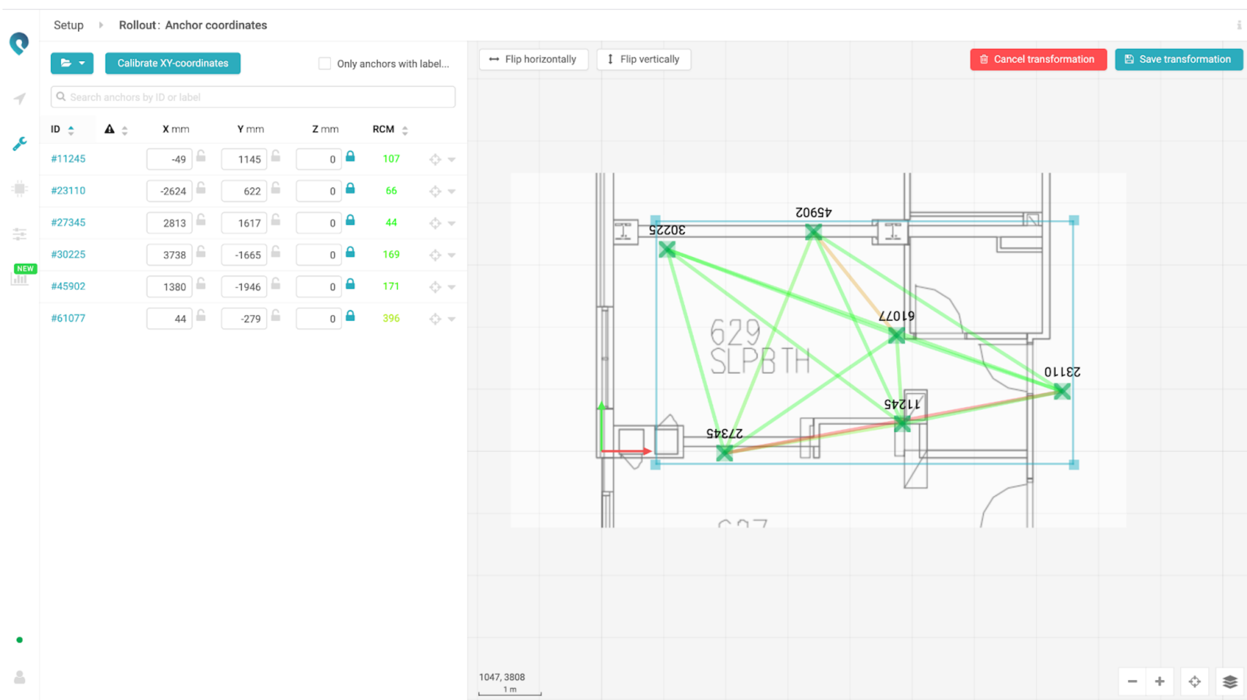


Figure 8.11. The screenshot of the Pozyx analysis app interface of setting up the six Enterprise anchors in the indoor trajectory experiment space (the green cross)
(photo credit: Sheng-Hung Lee)

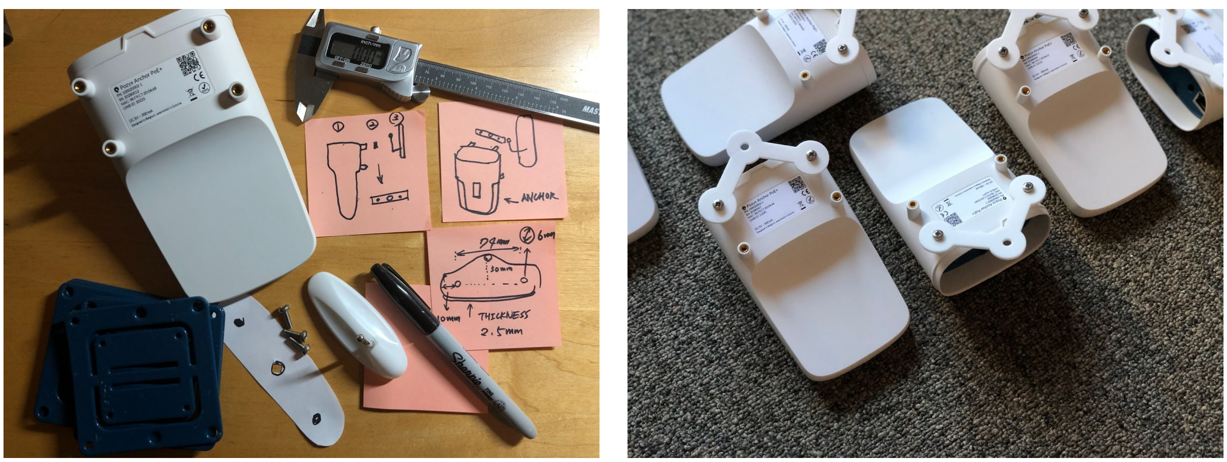


2) Install Enterprise anchors, other devices and software.

The devices included the hardware e.g., one Gateway (industrial positioning server) and six Enterprise anchors, and software e.g., web app, and analysis app to be set up to prepare to build an ideal RTLS environment. In order to successfully temporarily attach the six Enterprise anchors against the wall, we designed 3D-printed holders that can create an extra 5 cm of gap space to optimize the signal emission and also solved the problems of ethernet wire to connect six anchors on the wall (Figure 8.11. and Figure 8.12.).

Figure 8.12. Prototype how to attach six Enterprise anchors against the wall.
(photo credit: Sheng-Hung Lee)

Figure 8.13. 3D-print PLA stands designed for six Enterprise anchors against the wall.
(photo credit: Sheng-Hung Lee)



Besides the physical device installation, we also considered the software side. Due to the school (MIT) firewall and internet security issue, the device can't simultaneously transmit the data to the cloud for live analysis.

Another way around was to do the data connection locally. We used one independent laptop (Dell P124G) as the main server to analyze the data we collected from the six Enterprise Anchors. We can still get the same experiment result (Figure 8.14.). We also asked the Pozyx leadership team and technical experts: Vadim Vermeiren, Julie Neckebroek, and Aziza Paenen to give us suggestions about the set-up and the right conditions for RTLS and the indoor tracking devices.

In general, the installation process was a bit more complicated than we expected because of the internet safety regulation from MIT. After a 2-week preparation, we were ready to conduct the pilot test in the graduate student dorm for the next phase.

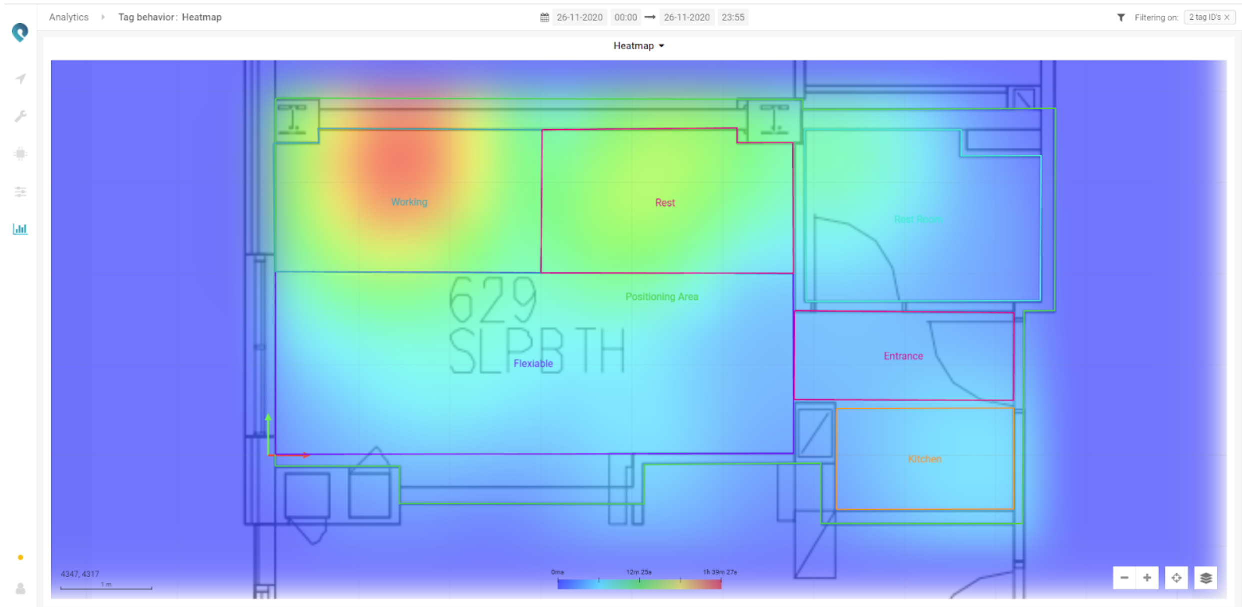
Figure 8.14. We use one laptop as a local server to connect six Enterprise anchors and wearable tags. (photo credit: Sheng-Hung Lee)

3) Learn how to use Pozyx analys app.

For software analysis, we meant to use the Pozyx analysis app with four analysis approaches: heatmap, spaghetti chart, zone analysis, and time budget (Figure 8.15.). Regarding heatmap, it was one intuitive data visualization tool to make researchers or designers quickly grasp the information of people's or things' movement to easily "read" the flow of the subjects in the space and thus suggest other better space layouts. Similar to the function of a heatmap, a spaghetti chart was another useful data visualization tool to capture people's real-time indoor trajectory.

The Pozyx analysis app also provided zone analysis. Based on the space floorplan we drew and uploaded to the software, we needed to define our discreet zones to specifically capture the movement of our observation subjects within the zones. Besides zone analysis, we can also calculate the time spent per different zones that we defined and also the frequency of people or things entering or learning zones.

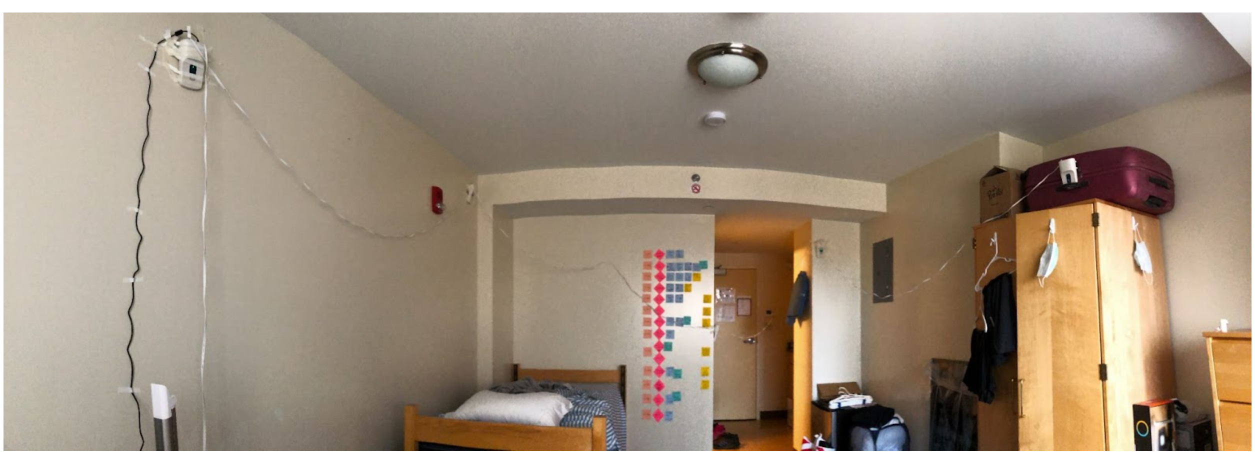
Figure 8.15. The Pozyx analysis app heatmap screenshot from the first-time pilot test (photo credit: Sheng-Hung Lee)



4) Conduct a pilot test to refine the process.

Once we measured the space, installed the devices and tested the software, we were to prepare to conduct a pilot test. The intention of the pilot test was to ensure that we had a set of rules to follow so that we can replicate the experiment under the same conditions to analyze the result. In this study, we did three-time pilot tests to fix some problems e.g., How to attach the Pozyx wearable tag or developer tag on the target users while they stayed in home? How to maintain the batter of the Pozyx wearable tag or developer tag during the 10 days' experiment?

Figure 8.16. The space sceen from the first-time pilot test (photo credit: Sheng-Hung Lee)



We also tried the tracking product of Oblu, a shoe-mounted indoor GPS technology company based in India, to test its indoor trajectory function. Oblu used the multi-IMU (MIMU) technology [149], on-board motion processing, and simplified interface to track people's or things' trajectories by applying Pedestrian Dead Reckoning (PDR) devices mounted on users' shoes to transmit location data from users' every step [118, 119].

After multiple rounds of testing and discussion with Amit K Gupta, Founder and CEO at Oblu.io, we found that the resolution of people's indoor trajectory was not high enough for us to analyze or meet our expectations. Their unique feature—multi-IMU (MIMU) technology was more suitable for the outdoor environment with long-distance tracking [152] e.g., GPS for automobiles (Figure 8.17.).

Figure 8.17. Photos of testing the tracking device and technology from Oblu
(photo credit: Sheng-Hung Lee)

<u>*5) Analyze the results and conclude the learnings.*</u>

We documented the indoor trajectory results on a daily basis and documented screenshots and video recordings of people's movements through the Pozyx analysis app each day. When we accumulated the 10-day data, we applied the software functions: heatmap, spaghetti chart, zone analysis, and time budget to analyze the result.

8.2.3. Analyze the Data and Testing Result

We used daily heatmaps paired with the spaghetti charts to analyze all the data we gathered from the tracking device (wearable tag). The observation was about the author's 10-day indoor trajectory experiment that documented the experience from two perspectives: movement and data ethics to reflect how we can design and plan better human-centered environment in the near future through assistive technologies.

The following two key learnings were generated from the data and our interpretation. The full document and story—Revisiting My Self-Quarantine Experience through a Data-driven Approach—were published in 2021 Design Management Institute (DMI): Review, a DMI journal that gathers articles and case studies around design, design strategies, methodologies [82].

1) Translate people's indoor trajectory into meaningful data to reflect people's needs.

Since the author had an indoor tracking device in the dorm for his master thesis project, the author decided to repurpose the device and apply it to track his ten days' indoor trajectory (Figures 8.18. And Figure 8.19.) to see the pattern in terms of the amount of time and frequency the author spent in different zones including the entrance, kitchen, rest zone, restroom, flexible zone (area for exercise), and working zone. The heatmap (Figure 8.20.) was generated from my in-home trajectories and showed how much time and the frequency I spent within different zones, which revealed the hotspots in my dorm room. It is an informative way to visualize data.

Figure 8.18. Pozyx analysis app screenshot of the indoor trajectory experiment

(photo credit: Sheng-Hung Lee)

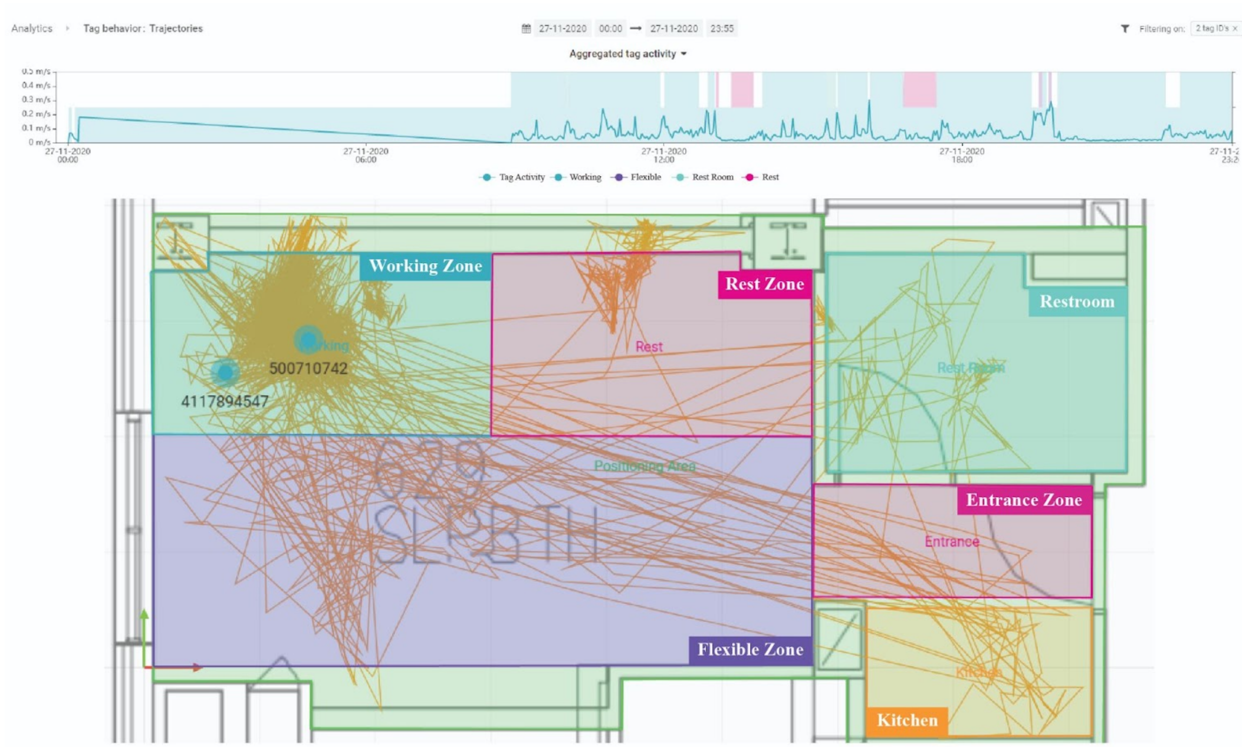


Figure 8.19. Daily (0:00~23:55) indoor trajectory screenshots from Day 2 to Day 10 of the indoor trajectory experiment

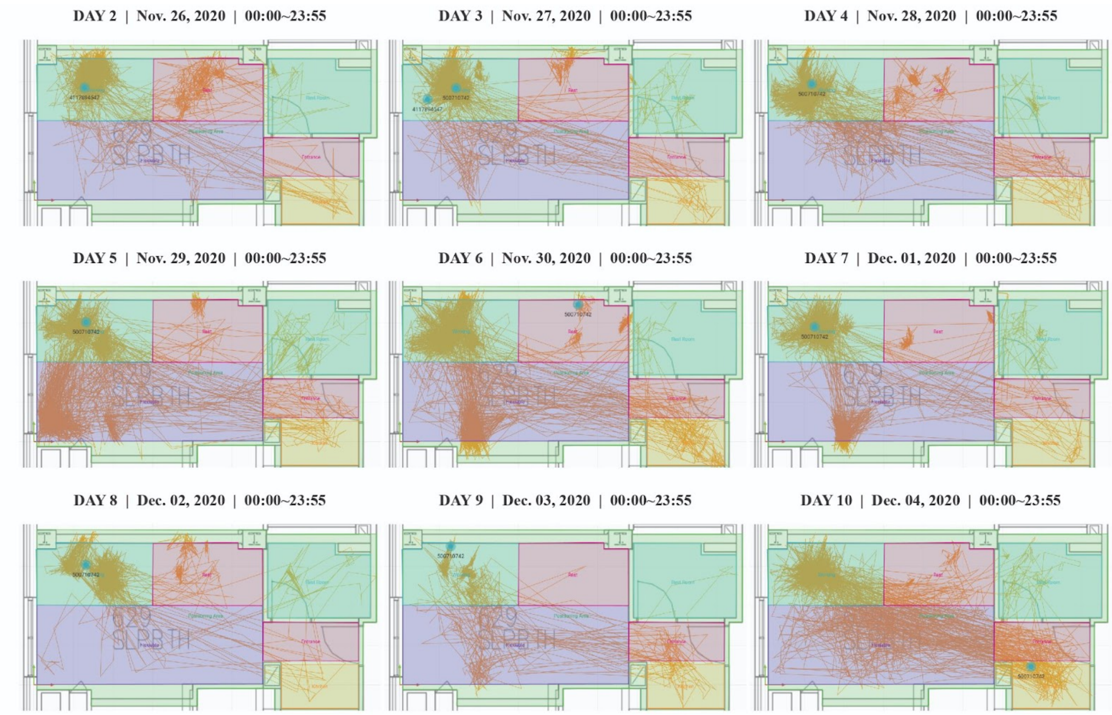
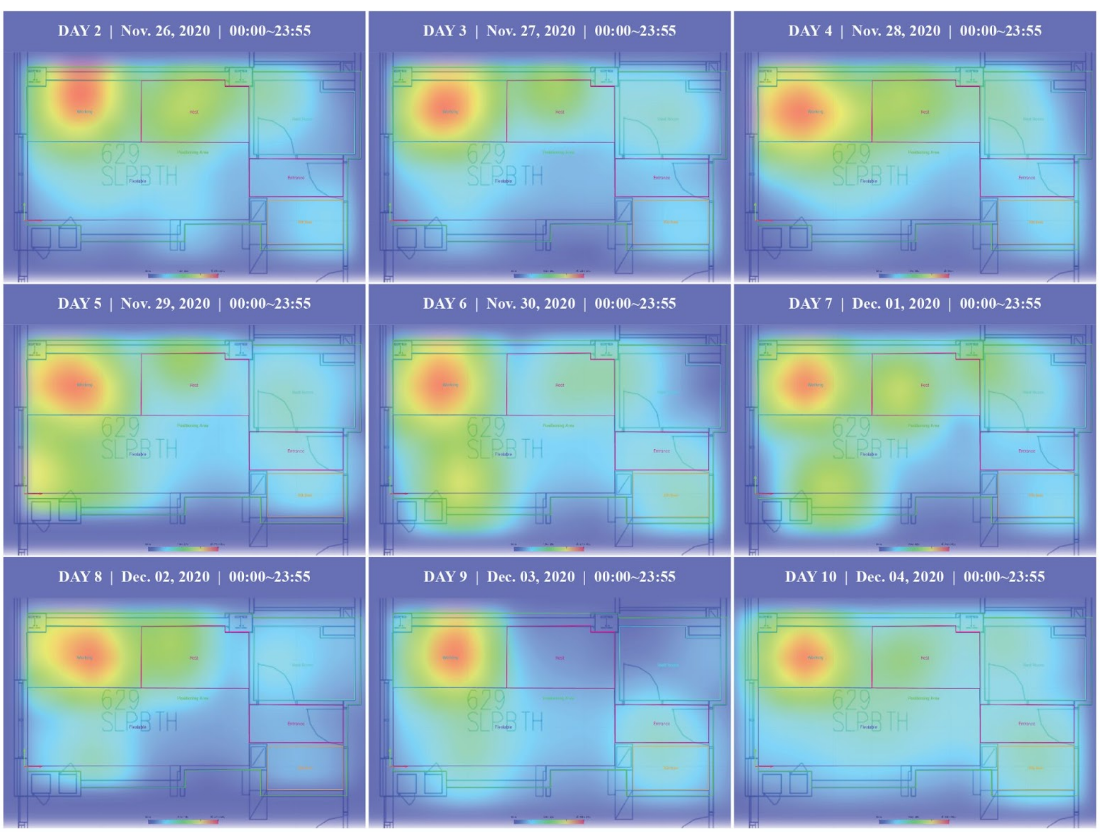


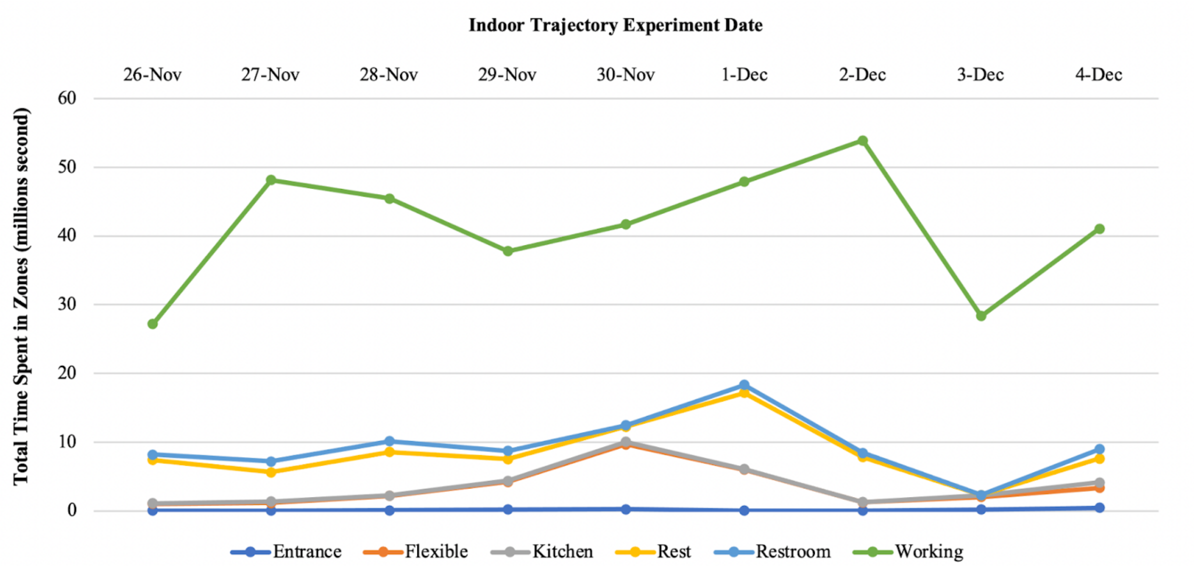
Figure 8.20. Daily (0:00~23:55) heatmap screenshots from Day 2 to Day 10 of the indoor trajectory experiment (hotspot is near work zone)



Interestingly, according to the data, the author spent most of the first five days in the working zone (Figure 8.21.). As the days passed, the author spent more time in the rest zone and kitchen. In revisiting the data, we found that the longer the author stayed in the dorm, the more time he spent wandering around between the kitchen and bed (rest zone), or just walking around (flexible zone) in order to release stress. We realized that keeping people busy with work was not that helpful or healthy. Assigning a decent amount of time for exercise and relaxation was much more effective. We all need some mental space and time to release pressure. Through the author's indoor trajectory data and experiment, in the future: How might we analyze people's indoor behavior movement data to help medical service providers predict people's mental health condition and needs during the difficult period of quarantine? If the data can predict someone's mental health/affective state, then we can perhaps give that individual a nudge and consider another question: What kind of nudge interventions can help people feel more positive?

Figure 8.21. Total time spent in different zones during the 10-day experiment

(photo credit: Sheng-Hung Lee)



2) Data Ethics—Capture data during the experiment in a respectful, responsible, and honest way.

Even though in this experiment we stored the data in the local laptop, we still need to be mindful of our data and how the company or the third party uses it. Given the high sensitivity of data that is collected about a user's personal health and indoor activity, how can we ensure that present and future operators of such tracking solutions maintain a high degree of ethics in the management of the acquired data?

The Little Book of Design Research Ethics by IDEO is a great source that briefly discusses how to seek and share learnings, insights, and observations about people's lives in an ethical way [153]. It is important to get the right data from people for the purpose of protection and safety. But we need to ask ourselves carefully how to retrieve people's data through a respectful, responsible, and honest approach. There is always concern for the data ethics that touch upon people's privacy and dignity.

8.3. Summary of Assistive Technology

Inspired by the assistive technologies discussed in Chapter 8, there are three essential insights: 1) design needs to reconsider users' dignity; 2) cultural differences influence people's behavior and design solutions; and 3) people's behavioral data can be translated into business opportunities, which can help us integrate this technology with computation design to generate a prototype as discussed in Chapter 9.

1) Design needs to reconsider users' dignity.

We knew that most IoT wearable product designs (e.g., smart watch, smart glasses) are designed to capture data from people and provide instant responses. The intention is to monitor people's health and safety by notifying users, their families or their medical team about various health conditions. The difficulty for design and engineering teams is to consider how designers can create products, services, and experiences that are not only functionally feasible, but also make people feel comfortable and safe with dignity. What IoT wearable product designs do and how they make people feel are equally important in the context of design.

For example, how to protect people's data privacy regardless of storing their data on the device locally or on the cloud; how to design the product for older adults by taking out the label of "senior" or "elderly"; and how do designers create a respectful interaction, service, and experience between product and users are all key questions to ask.

Human-centered design does not mean we identified users and then used that to attach labels on our target users through design. In the study, we used indoor footwear design for older adults as an example to consider the user's emotional experiences as representative of opportunities for further product design and development.

2) Cultural differences influence people's behavior and design solutions.

The definition of indoor space varies from person to person, especially when considering the context of different cultures, societies, and countries. When we conducted user interviews, we kept hearing our participants say: they do not wear slippers at home; they do not take off their shoes indoors; or how do you define indoor or outdoor space when all spaces are considered "home space" to them. All of these make us evaluate the role of culture in shaping these perspectives. For example, perhaps product design should think about different modules and features catering to multiple cultures and needs of our users to come up with different versions of storytelling including the language we want to use, and the content we want to craft, to sell the products in different markets.

3) Translate people's behavioral data into business opportunities.

Besides tracking people's movement, we can also use indoor footwear to better understand users' in-home environments through capturing their frequency of entering certain areas, health conditions, fall detection, as well as other critical behavioral data. More importantly, we might analyze and translate more of these unconscious behavioral data into business opportunities to map out and re-imagine the design of indoor and outdoor spaces in the home. With this synthesized data, the space we are going to renovate in the future is based on people's behavior, rather than on just aesthetics or architects' taste. This represents a more scientific approach to redesigning a human-centered space.

Chapter 9. Computational Design and Prototype

In Chapter 9, we discussed the two design concepts: inclusive design and computation designs, and how these different design processes influence our indoor footwear design for older adults, why this is relevant to our research, and what other indoor footwear design applications are inspired by inclusive design and computation design.

9.1. Inclusive design footwear prototype collaborated with Arts at MIT, MIT Wiesner Art Gallery, and MIT AgeLab and we displayed partial design outcomes at DESIGN: INCLUSIVE exhibition located at MIT Wiesner Art Gallery from February 14th to March 12th, 2022 (Figure 9.1.). 9.2. Computational design experiment was partnered with nTopology to test the early footwear sole concept through people's feet pressure data.

Figure 9.1. Inclusive design footwear prototypes and posters at DESIGN: INCLUSIVE exhibition (photo credit: Justin Knight)

9.1. Inclusive Design Footwear Prototypes

We explored the idea of inclusive footwear for older adults. Inclusive footwear is about one-size-fits-one. It's about creating a personal walking experience that can fit people's current needs while adapting, evolving, and changing as they age and their context changes. Inclusive footwear design is deeply personalized, but it is also malleable.

We prototyped seven design expressions via 3D printing made of PLA material. Design expression is an experimental way to demonstrate our creative process. When we designed seven different types of footwear soles, we synthesized the previous literature, interviews and surveys with users and experts, and our experience and observation (Figure 9.2.).

Some key questions came to mind. How do we make product split lines to reconfigure each component of footwear soles to make it ergonomically functional and aesthetically appealing to users? How do we strike the balance between design expression and art expression according to the needs of users? How do we leverage the state-of-the-art technology, e.g., additive manufacturing, to disrupt the creative processes that designers or engineers normally use?

Figure 9.2. Seven inclusive design footwear prototypes (photo credit: Justin Knight)

9.1.1. Background Information

In a fast-paced society, our life and behavior have been transformed by state-of-the-art technology, politics, advanced healthcare, social justice, environmental change, and much more. In the midst of these large, complex, and systemic challenges, we need to keep reflecting and asking ourselves: Whose voice is (and continues to be) missing? Who in our society has been deemed vulnerable or less powerful? Which groups of people face the largest degree of exclusion?

With "Inclusive Footwear Design for an Aging Population," we want to uplift the power of inclusive design by reimagining the future of footwear for older adults and those of us who are growing older each day. This has resulted in seven design expressions that originate from the intersection of arts, engineering, science, and design. We believe that this intersection can work to spread awareness and promote acts of inclusion (and love). This is an engine for innovation.

9.1.2. Creative Process

Based on the literature review in Chapter 2, the user survey, and the iterative design process, we performed a series of exploratory art experiments that represented potential shapes of seven footwear forms. These prototypes emphasized the sock liner with multiple design patterns. This enabled us to consider how users were thinking about the requirements needed to make inclusive footwear for current older adults and for those who hope to become older adults. The seven conceptual design expressions are considered an outcome of the project.

Kat Holmes, former Director of User Experience Design at Google and author of *Mismatch: How Inclusion Shapes Design*, shared her definition of inclusive design at the 99U conference in 2019: “It doesn’t mean we design one thing for all people. It means we’re designing a diversity of ways for people to participate in a place with a sense of belonging. And that goal is beyond access; access is absolutely the fundamental and the starting point, but that shared sense of contribution to one another in a place itself is an outcome of design that starts with recognizing mismatches**.** ” [154]

We explored the topic of inclusive design in the context of redesigning footwear for an aging population, which inherently allowed us to think through what inclusive design means in this context. We considered our extreme user group to be older adults aged 61 years and above, but we were also interested in hearing from those in younger age groups to better understand how they might anticipate footwear needs for their future selves. From engaging in this research, we learned to be empathetic while considering the design challenge at hand: how can we better include people’s behavior, life rituals, and senses of sight, hearing, speaking, smell, and touch as a part of their experience with footwear?

Inspired by Kat Holmes’s book [155] and speech, six key questions guided our exploration with our target users: 1) How often should this design research involve continuous and iterative cycles? 2) Why do we make critical design decisions in product development? 3) Who uses or consumes the design outcome and services? 4) How are the product, service, and experience created in the design process? 5) Who are the teams and key stakeholders involved in the design work and who participate in the design process? and 6) What do we create through the product, service, and experience that makes an invaluable positive social impact?

9.1.3. Why—Listening to People

We collaborated with the MIT AgeLab to design a two-week online questionnaire conducted in 2021 (Chapter 6). The resulting sample size included 495 results and were categorized into three primary age groups: Group A were participants aged 18 to 30 years old (37.4%), Group B were participants aged 31 to 60 years old (33.0%), and Group C were participants aged 61 to 100 years old (29.6%). Table 6.1. in Section 6.2.1. contains more details.

The purpose of the user survey was to gather participant's diverse perspectives to inform the footwear prototype design process. Here, we presented four selected survey results focusing on the functional aspects of footwear designs. We asked:

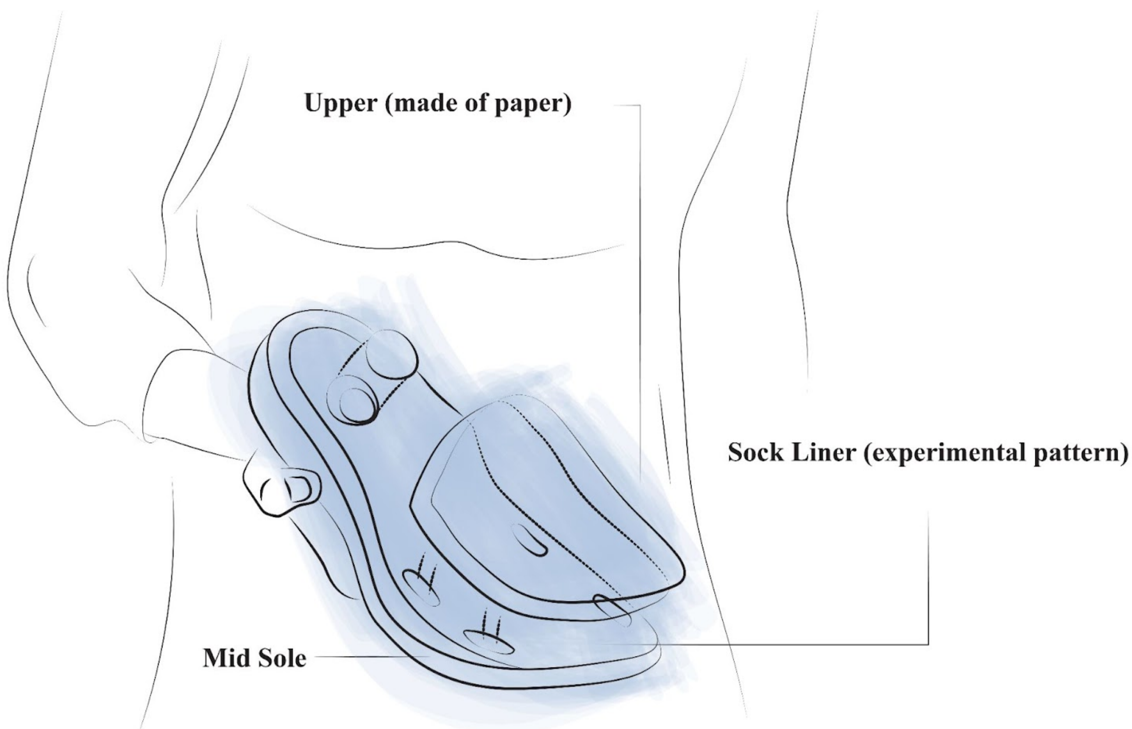
- Imagine in the future if you were to have a pair of high-end or better quality indoor footwear, ideally, which professional services and experiences would you be the most interested in having with regard to your indoor footwear? The result is shown in Figure 6.17. (Appendix H: survey question 3.29.).
- Which of the following functions would you want an IoT wearable device (not just a pair of smart indoor footwear) to help you with? The result is shown in Figure 6.25. (Appendix H: survey question 5.5.)
- What sort of things do you think smart footwear could do for you? The result is shown in Figure 6.26. (Appendix H: survey question 5.7.)
- If you had a pair of smart indoor footwear, what functions would you want the footwear to have? The result is shown in Figure 6.27. (Appendix H: survey question 5.8.)

Figure 9.3. Design expression 1 and 7 footwear prototypes at DESIGN: INCLUSIVE exhibition (photo credit: Justin Knight)

9.1.4. How—Inclusive Footwear Design Experiment

We decomposed the concept of inclusive footwear design for an aging population into three components: upper, sock liner, and midsole (Figure 9.4.). For the purposes of this section, we emphasized sock liners to explore how different design patterns on sock liners could influence people's behavior to control the hypothetical functions of smart footwear. Here, we not only considered the functional requirement of the design, but also the overall look and feel to ensure the user's experience would be comprehensively accounted for—from function to emotion, the logic, and the aesthetic.

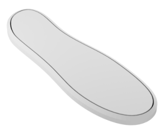
Figure 9.4. Explosive view of inclusive footwear prototype
(illustrated by Sheng-Hung Lee)



9.1.5. What—Seven Inclusive Footwear Design Expressions

For each design expression, we concluded its description with one How-Might-We question (HMW question) and five keywords to help us clearly explain to participants our thinking process and design motivation in detail in Table 9.1. There is no actual sequence of each design expression, but they all originated from the design expression 1.

Table 9.1. Seven design expressions of footwear sole
(designed by Sheng-Hung Lee)

Design expression	Concept description	HMW question	Key words
Design expression 1 	This is the form foundation of the footwear sole designed for an aging population. The other six design concepts are based on this footwear archetype. We used ordinary people's foot shape as a base with the edges of a 45-degree angle chamfers.	How might we generalize the dimensions of people's feet from different nationalities, races/ethnicities, genders, and ages in an inclusive approach and integrate a footwear technology component designed to age with users?	footwear archetype, generalization, inclusive, integration, technology
Design expression 2 	The concept was inspired by an oval shape from nature. We used its design language to carve out the split line of the footwear sole divided into six areas. We wanted to make the design in general to not only achieve its functional requirement, but also visually and ethically appeal to people who put it on.	How might we design footwear elements from and inspired by mother nature to help designers come up with wilder innovative solutions or universal design options?	nature, universal, ideas, innovation, inspiration
Design expression 3 	This concept applies organic lines to the sole of the footwear. We wanted to discuss how comfortable it can be when people control the functions of their footwear through their sole and how the comfort level can affect the accuracy of controlling the functions based on six different sizes and positions of control areas.	How might we create an adaptive organic shape of a footwear sole that makes older adults' feet comfortable and also look and feel elegant?	organic, shape, adaptive, comfortable, elegant
Design expression 4 	The concept was inspired by the idea of the grid system. We created multiple heights with a two centimeters' difference as a unit to create various volumes of rectangular cubes. Our intention is to simplify the design language to highlight the functions of footwear.	How might we utilize simple and clear design languages to navigate the footwear design process while designing for large, complex human problems?	grid system, simple, complex problems, design process, language
Design expression 5	Concept 5 is a mix of design expression 2 and 4, which consists of an organic element and a grid system. We experimented with the idea of "conflict" in terms of form and	How might we distill the essence of "conflict" to build a playful and accessible footwear design for an aging	conflict, contradictory, mix, playful, accessible

	function: partition lines are divided areas based on different functions with the curvy surface on their top. We want to know the extent to which this idea is acceptable to our target user group—older adults.	population?	
Design expression 6 	The concept was inspired by the idea of foot acupuncture points. We are trying to use cylinders in a variety of diameters, heights, positions, and materials to imitate the different levels of foot pressure points when people put on their footwear soles. We explored whether the different foot pressure points can be intuitively utilized to control footwear designed for an aging population.	How might we reimagine the way older adults sense the world around them through the pressure of each footstep to control and capture their moments in life?	pressure control, acupoint, sense, footstep, moment
Design expression 7 	We used the triangle framework as a stable structure to map out the footwear sole surface. The concept is to test if this is the most cost-efficient way to divide the functional area of the footwear sole. Nine divided lines of the triangle indicated the flexible degree of the surface when people put it on.	How might we find a cost-efficient footwear design option for older adults in terms of the stability structure of the sole and people's behavior to control the functions of smart footwear?	cost-efficient, triangle, stability structure, behavior, control

Figure 9.5. Design expression 6 and 7 footwear prototypes (photo credit: Justin Knight)

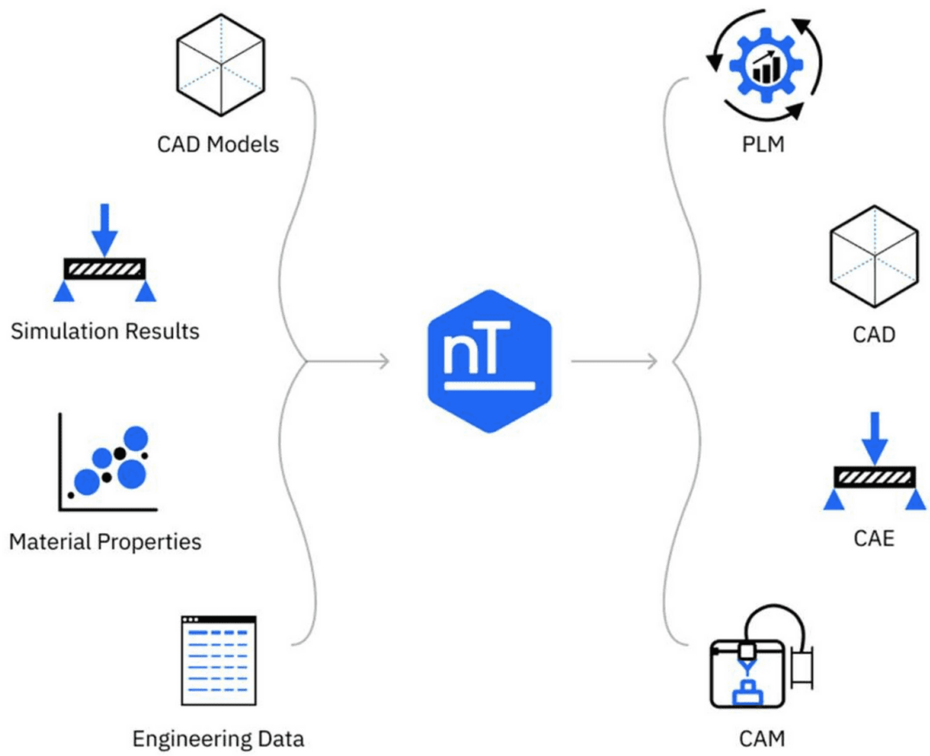
9.2. Computational Design Experiment

9.2.1. Field-Driven Design Approach

We experimented with a field-driven design approach to prototype tailor-made footwear soles for older adults. From the research of nTopology, we defined a value of each point of 3D space as a field. For example, a field can represent a set of spatial data of physical quantities, such as temperature, stresses, or flow velocity in engineering studies.

For design studies, many engineering and design applications focus on 3D modeling. These types of data are usually like scalar numbers. We can use nTopology software to translate them into scalar fields: tensor fields, vector fields, and Boolean fields. Fields can be modified by basic math operations–addition, subtraction, multiplication, and division–to either make them simpler to adapt to our needs or create more complex interactions (Figure 9.6.).

Figure 9.6. nTopology serves as a platform-type of software to translate and integrate other CAD files into implicit modeling (the diagram was from the nTopology website)



To offer a better understanding of the difference between the field-driven approach and traditional CADing, we made a comparison of them in Table 9.2. to show both methodologies' pros and cons with examples.

We also published this part of the research and design finding—computational design experiment for older adult's footwear at DesignWanted, an international digital media company with a design focus, under the category of technology in 2022 [156].

Table 9.2. Two models of CADing comparison
(the table originated from the published paper [157])

	Traditional CADing process	Field-driven approach (focusing on implicit modeling)
Pros	● Build relatively simple CAD models such as product design, furniture design. ● Easy to track each CADing step, since its command follows linear and logical process. ● There are many CADing files/templates that designers or engineers can use. Some companies have already established virtual CADing libraries for reference.	● Decrease the size of CADing files efficiently. ● Automatically translate test object's data into CAD models through algorithms or AI. ● Software can be compatible with other CADing software. ● Each CADing command is modular-based and gives designers or engineers more flexibility to play with. ● The software is designed to create or solve complicated geometry forms. ● Designers or engineers can see the simulation result in real time.
Cons	● Must manually control CAD models and take time to modify them. ● Hard to work on the same 3D model collaboratively.	● Need to consider the criteria to measure and calibrate the design result in advance. ● There are fewer CADing files/templates that designers or engineers can use.
Example	● SOLIDWORKS [158] ● Rhinoceros 3D [159]	● nTopology (implicit modeling) [76, 106] ● Oqton (AI-driven manufacturing) [160] ● Siemens NX (intelligence driven design) [112, 113]

9.2.2. Experiment Process and Challenges

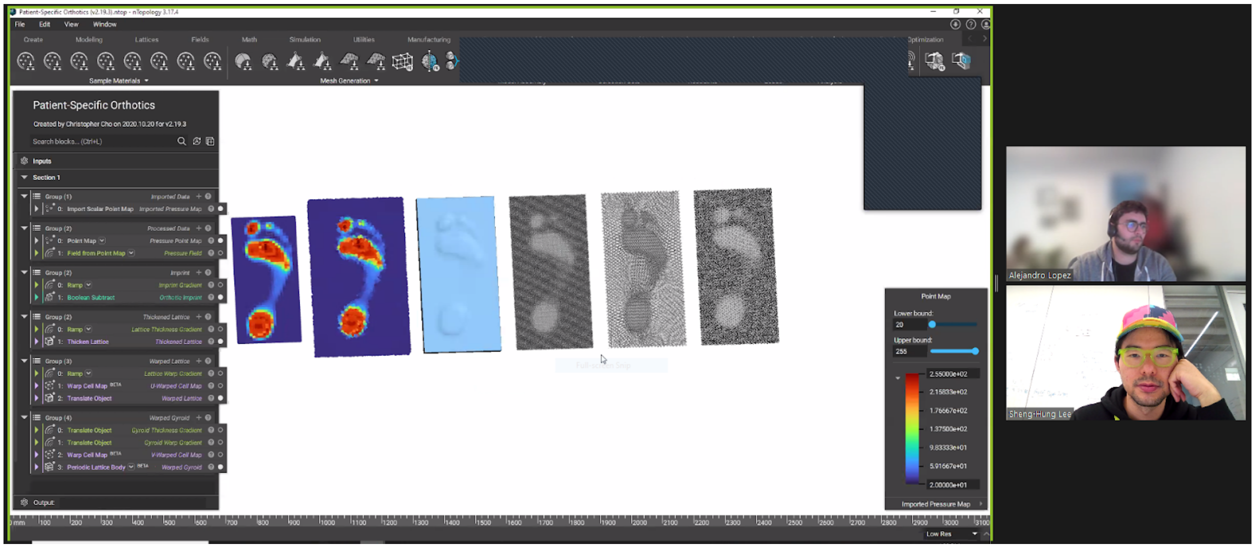
In this section, we worked closely with Alejandro Carcel Lopez, EMEA Senior Application Engineer at nTopology Inc., to understand the process and principles to help us create our own version of soles by applying data (Figure 9.7.). However, we used the existing material (people's foot pressure data) from the nTopology example to remap it to fit the sole of our new indoor footwear design to simulate our hypothesis.

One key challenge lies in how to remap the pressure map data to the new shape of the sole. When we used nTopology software, there were many steps to adjust the pressure map's shape to the new sole design.

Due to the pandemic and the scope of the project, we didn't have a chance to measure the older adults' foot data directly from the field research. For further study, we wanted to establish a series of human footwear data libraries for older adults including their foot dimensions, shapes, and some observations and insights to enable future footwear designers and medical teams, e.g., family doctors to gain comprehensive materials to refer to.

Since this is a three-week experimental approach, we didn't have enough time to consider how to capture the data from participant's feet as important input and process the data by translating it into accurate and useful information that designers or engineers can reference as a great starting point.

Figure 9.7. Translate people's feet pressure data into footwear soles design with complex lattice structure and designs. (co-worked with Alejandro Carcel Lopez, EMEA Senior Application Engineer at nTopology Inc. and published by DesignWanted Magazine [156])



Besides using people's feet pressure map data to translate it into footwear sole design, we also tried different parameters of our indoor footwear CADing model in nTopology to rebuild the sole of the indoor footwear model to prototype six products structures. A further step is that we can use this computational design result to test older adults. Tables 9.3. to Table 9.7. documented our experimental process by tweaking longitude count, latitude count, radius cell size, approximate thickness, approximate bias length, and fill type. Table 9.3. (Design expression 1) was the fundamental model of the indoor footwear sole that we stared to protoype with.

Table 9.3. Indoor footwear sole simulation 1 (designed by Sheng-Hung Lee)

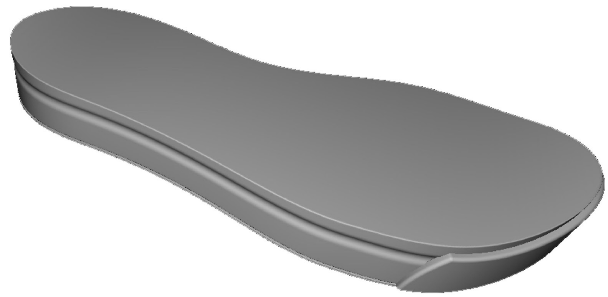
Simulation 1—Indoor footwear sole		
Longitude count	n/d	
Latitude count	n/d	
Radius cell size	n/d	
Approx. thickness	n/d	
Approx. bias length	n/d	
Fill type	n/d (base)	

Table 9.4. Indoor footwear sole simulation 2 (designed by Sheng-Hung Lee)

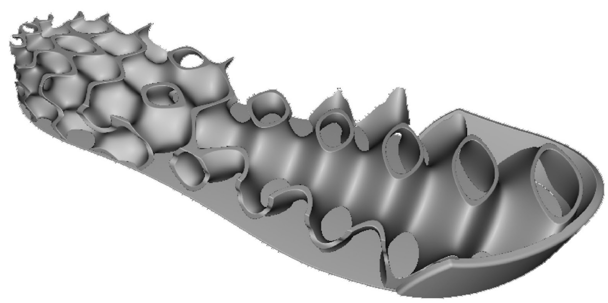
Simulation 2—Indoor footwear sole		
Longitude count	20	
Latitude count	20	
Radius cell size	20	
Approx. thickness	1	
Approx. bias length	0	
Fill type	Schwarz	

Table 9.5. Indoor footwear sole simulation 3 (designed by Sheng-Hung Lee)

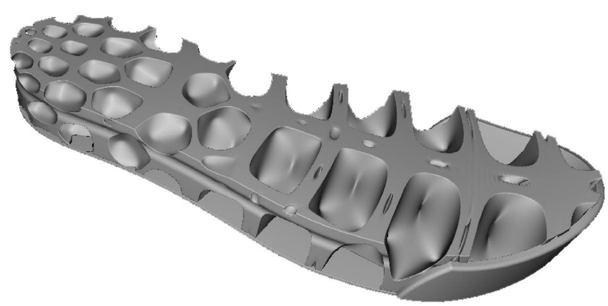
Simulation 3—Indoor footwear sole		
Longitude count	20	
Latitude count	20	
Radius cell size	20	
Approx. thickness	1	
Approx. bias length	0	
Fill type	Neovius	

Table 9.6. Indoor footwear sole simulation 4 (designed by Sheng-Hung Lee)

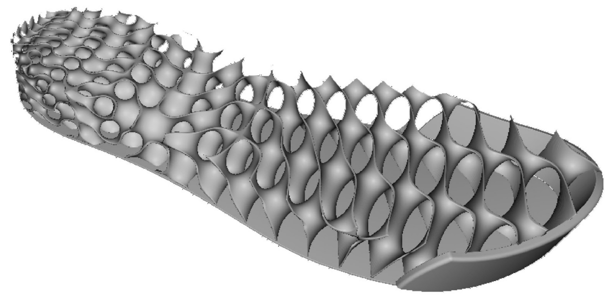
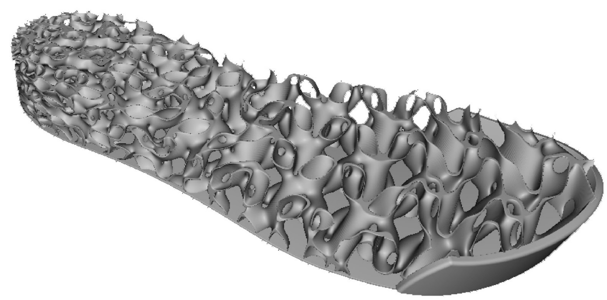
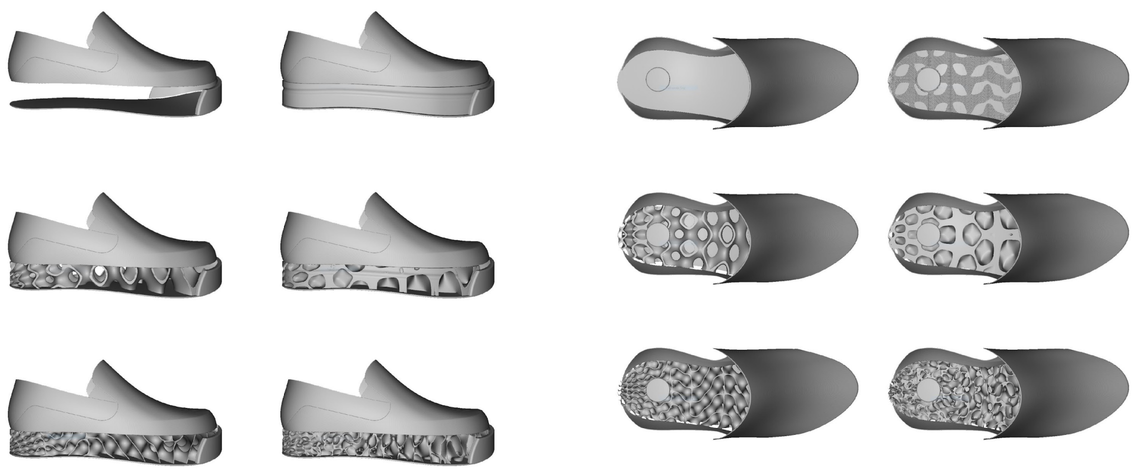
Simulation 4—Indoor footwear sole		
Longitude count	20	
Latitude count	20	
Radius cell size	20	
Approx. thickness	1	
Approx. bias length	0	
Fill type	Diamond	

Table 9.7. Indoor footwear sole simulation 5 (designed by Sheng-Hung Lee)

Simulation 5—Indoor footwear sole		
Longitude count	20	
Latitude count	20	
Radius cell size	20	
Approx. thickness	1	
Approx. bias length	0	
Fill type	Lidinoid	

The indoor footwear sole experiments had made us think of the potential design value to apply older adults' foot-pressure data to the CADing process. Designers or engineers can easily change the numbers, structure, and dimensions of latitude by tweaking parameters in the software to create and tailor-make footwear soles for older adults. This not only might save more time investing in product design and development process, but also precisely control the expected design quality to make the design outcome more inclusive (Figure 9.8.).

Figure 9.8. Side and top views of six indoor footwear computational design ideas
(designed by Sheng-Hung Lee and published by DesignWanted Magazine [156])



9.2.3. Summaries and Future Opportunities

In this experimental approach, we found the following three key takeaways of applying a field-driven approach from nTopology software: 1) Create affordable tailor-made services, 2) Leverage software compatibility, and 3) Enable adaptive model building workflow, which benefits us in designing better indoor footwear for older adults and discussing the future digital design modeling opportunities (Figure 9.9.).

1) Create affordable tailor-made services.

The field-driven approach has made the CADing process more efficient, especially when designers or engineers work on complicated 3D models, e.g., use complex lattice designs to optimize the structure. The increased speed achieved for CADing through a field-driven approach has enhanced the benefit of faster iterations: the potential opportunity of tailor-made footwear design, which allows us to try various versions in a short time catering to different users' needs. For example, we used one participant's foot pressure data to specifically create his/her footwear soles to alleviate his/her foot pain issue.

For future research, if we can measure customers' feet before they purchase footwear, they will receive not only their own tailor-made footwear soles but also shoes whose style, pattern, or colors provide a more personal and comfortable wearing experience. The field-driven approach can offer customers an affordable tailor-made footwear service and might disrupt the current footwear design and manufacturing process and increase user expectations.

2) Leverage software compatibility.

Unlike traditional CADing software designing for building 3D models, nTopology software and its field-driven approach are more like providing a platform with great compatibility by integrating with other 3D software, e.g., SolidWorks and Rhinoceros 3D.

In short, nTopology can import various file types and build on existing CADs, designs, or prototypes to improve its engineering performance or aesthetics. The software compatibility has greatly maximized the power of field-driven design, giving designers or engineers the flexibility to integrate their 3D models effortlessly. The field-driven approach can show its software compatibility to provide an open platform to foster creativity.

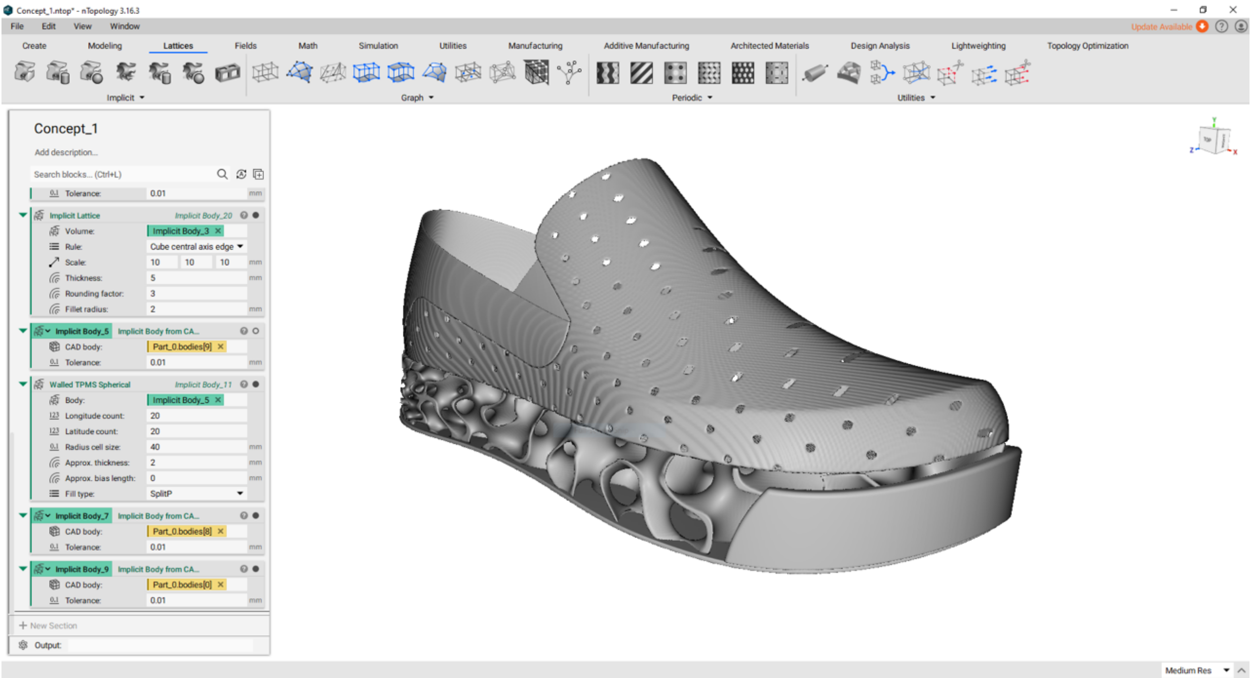
3) Enable adaptive model building workflow.

Another benefit of using a field-driven approach is the adaptiveness and scalability of nTopology workflow. Design or engineering teams need only set up one main workflow that can correlate measurable data, e.g., people's feet pressure data, so that nTopology software can build automatic solutions based on different parameters e.g., environment conditions, materials features, temperature.

Therefore, the main cost of design efforts will lie in building the one main workflow to solve various complex geometries models and create new design possibilities that are impossible to CAD or import from traditional CADing software. Adaptive workflow saves people much time from routinely manual tasks, e.g., model programming, because nTopology software can do such tasks better due to its well-designed AI algorithm.

For example, one French company, Medical 3D, has applied the adaptive and scalable features of the software to their medical-product 3D-printing business: custom orthotics, veterinary prostheses and other software solutions [163]. They use a field-driven approach in customized and automated product printing processes so that they can provide more tailor-made printing services with not only less time in design and manufacturing but also more robust structural design and optimization to benefit more patients who need the medical product printing service.

Figure 9.9. Envision future indoor footwear design for older adults by using a field-driven approach. (designed by Sheng-Hung Lee)



9.3. Summary of Prototype Experiments

We prototyped seven inclusive footwear design models and one computational footwear sole to help refine the early design concepts that originated from the literature review, survey, interviews, and participatory workshops. In this prototype stage, we not only validated some of our early hypotheses, but also explored different ways to articulate our ideas through media or software. We have come up with the following three key benefits of this prototype experiment: 1) the advantage of rapid prototyping, 2) the benefit of computational thinking, and 3) an evaluation of the creative process compared with HCSD in the present study.

1) Master the power of rapid prototyping: fast and low cost.

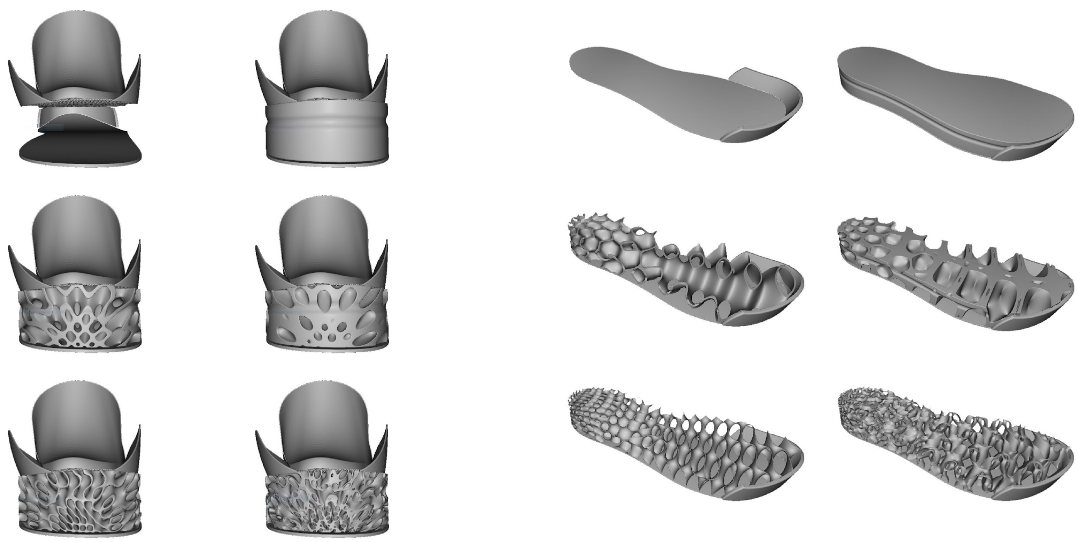
A prototype is a fast and interactive process, which can help designers or engineers efficiently test potential design ideas in low resolution before companies make huge investments in the manufacturing process. The sooner we tested our design, the more quickly we identified present problems at a relatively low cost. In the study, we emphasized prototyping for early-stage concepts. Our intention was to learn whether the concepts meet older adults' expectations to address their pain points and how they can help us refine ideas.Since this was a three-year master's thesis project, there was not a plan to build the manufacturing capability of the prototypes, but further study can take this manufacturing stage into consideration.

2) Infuse data and computational thinking into the design process.

We assumed that when we integrated users' behavioral data (e.g, indoor trajectory trace, health condition information) and the computational features with designers' experiences and intuition, our design process would become not only more powerful in terms of accuracy (e.g., expected test results, project deliverables) and efficiency (e.g., response time, labor cost) but also meaningful to reflect people's needs, which realized the ideal design outcome (Figure 9.10.).

There were still many components we needed to test to validate the above assumption. In this chapter, we discussed the design outcomes from the seven inclusive design models and computational footwear sole prototype to reflect our current design process and the possibility to combine with HCSD.

Figure 9.10. Back views and soles of six indoor footwear computational design ideas
(designed by Sheng-Hung Lee and published by DesignWanted Magazine [156])



3) Creative process integrating with Human-Centered System Design (HCSD).

To continue with point 2, we were also curious to discuss the connection between HCSD and computational thinking (e.g., the field-driven approach and data), and how we can mutually integrate or curate them reasonably. In dealing with data-related problems in particular, although we know how to capture data from our target users (e.g., older adults), we also need to learn how to make sense of data from users' perspectives or key stakeholders' angles where this could be an entry point for applying HCSD.

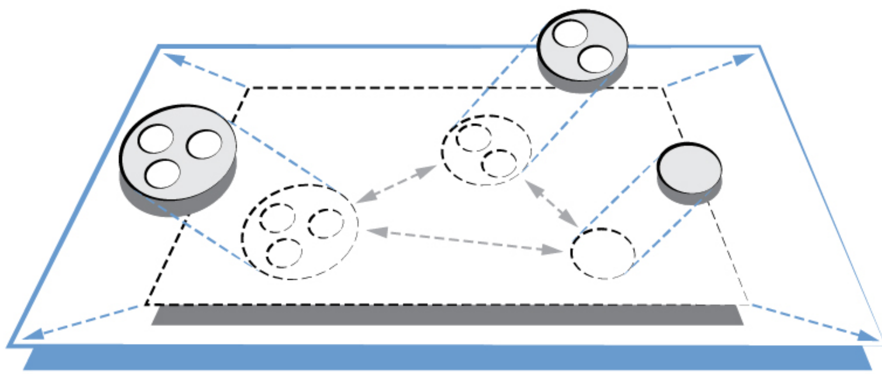
When we prototyped seven inclusive footwear design models and experimented with footwear soles by using a field-driven approach, we had already conducted user research to understand people's needs as a transition moment into the design and execution mode. This might be a critical step that most people will overlook before jumping into the design. Regardless of using an inclusive design or a computational approach, HCSD is the framework for understanding people's needs as the priority.

In order to make creative processes and computational thinking successfully integrated with HCSD, understanding users' desires is a critical starting point. In this study, we started by clarifying older adults' needs in Chapter 6.

Chapter 10. Discussion and Conclusion

In this thesis, we covered different but interconnected aspects in the nine chapters: literature reviews, surveys and interviews of users and experts, hybrid participatory workshops, assistive technology, computational design, and product prototyping to help us informatively reimagine the future of indoor footwear products, services, and experiences for older adults.

Figure 10.1. Amplify Human-Centered Design solutions in systematic approaches.
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



In applying HCSD methodology, we experimentally explored the following three points:

1. How do we define HCSD methodology concisely by refining traditional HCD processes focusing on product design and integrating SE and SA methodologies?
2. How do we precisely translate ideas and concepts inspired and contributed by participants by using HCSD methodology from inspiration, ideation to implementation to reflect on people's desirability, engineering feasibility, and business viability?
3. How do we conduct immersive user interviews with older adults through remote technologies paired with HCSD methodology?

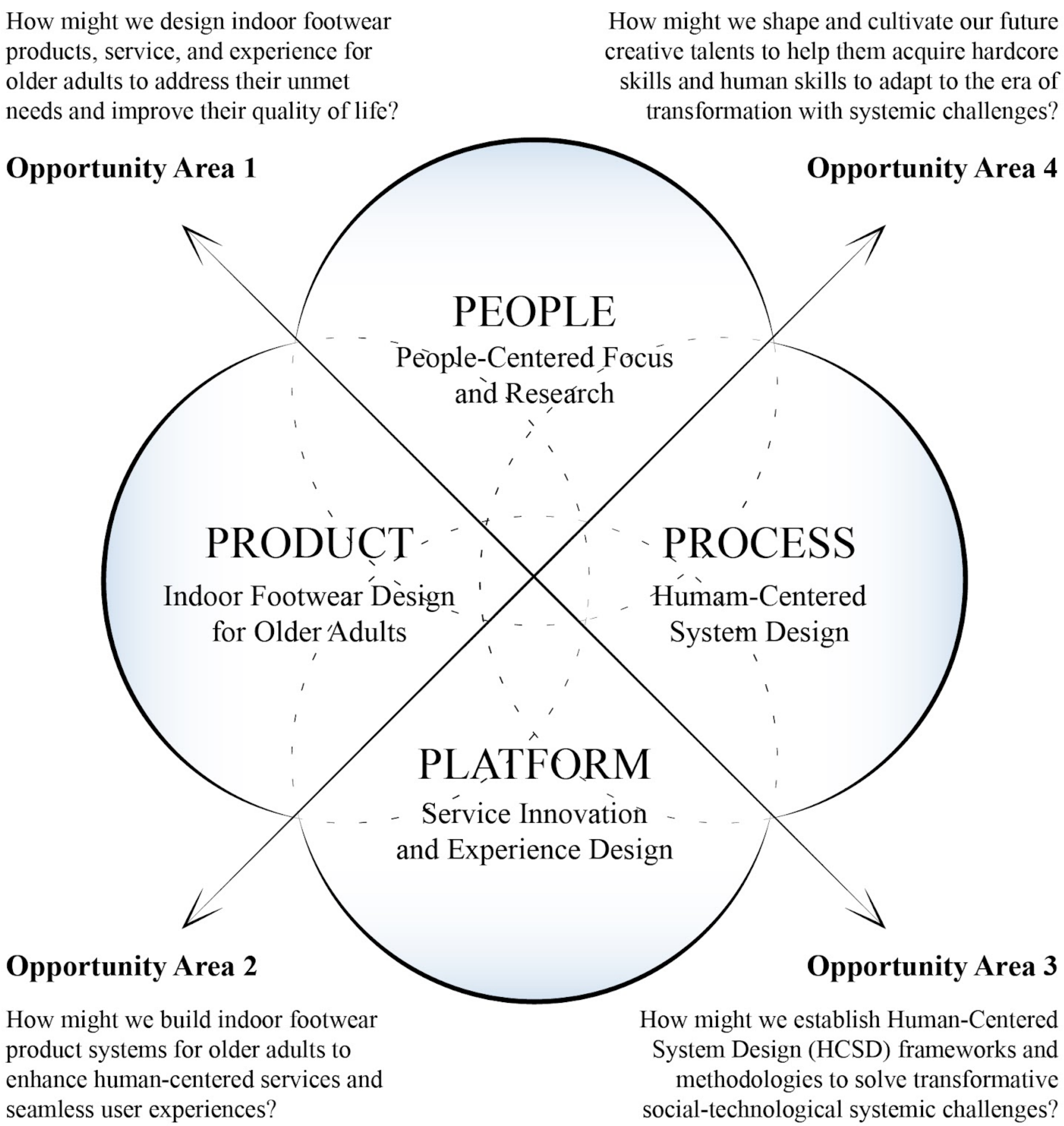
Regarding examining the topic of indoor footwear design for older adults, we discussed the following four research questions:

1. What comprehensive design evaluation considerations do designers and engineers need to design optimal human-centered indoor footwear for older adults?
2. How do we plan, design, and execute business and design strategies for indoor footwear design for older adults?
3. How do older adults perceive and use IoT wearable devices? What are their perceptions of IoT wearable devices (e.g., smart IoT indoor footwear)?
4. What are the roles, definitions, and relationships of indoor footwear design for older adults in the context of future smart homes?

10.1. Thesis Summary

We concluded four main perspectives from this thesis project: 1) people, 2) product, 3) platform, and 4) process to help us comprehensively understand the topic—Human-Centered System Design for an Aging Population: An Experimental Study of Footwear Design. In addition, we propose four opportunity areas inspired by the above four perspectives for future studies in Figure 10.2.

Figure 10.2. 4Ps perspectives to discuss Human-Centered System Design (HCSD) and its indoor footwear design implementation (illustrated by Sheng-Hung Lee)



10.1.1. People—People-Centered Focus and Research

We defined people in this context as older adults and we summarized their behavior into wearing behavior, purchasing behavior, and other relevant observations as captured from the literature reviews, user interviews, and surveys. Chapter 5 and 6 documents more detailed information for reference.

1) Build a people-centered product service and related sustainable business models.

In general, we found the majority of older adults and their caregivers (e.g., children and grandchildren) did not have opportunities to access knowledge about how to choose suitable footwear or indoor footwear for themselves or their family members. This also reflected the fact that not many people understood the importance of indoor footwear service design, as shown in Figure 6.17. We provided descriptions of future service design concepts and tested it. The survey result didn't show the high percentage of users' needs of having footwear services across three different age groups. We also selected 10 participants to ask about their perception of footwear service, which also didn't show their strong interests.

The diagram exhibits that those survey participants did need an ideal pair of good quality indoor footwear. The challenge for designers and engineers lies in creating a great quality indoor footwear product design for users (e.g., older adults), while offering a people-centered product service, (e.g., after-sale service), by considering sustainable business models for indoor footwear service providers.

2) Identify users wearing indoor footwear that differ from people purchasing them.

According to the survey results, the majority of users were the same people who purchased indoor footwear. Figure 6.19. shows the opposite: 52% of Group A, 25% of Group B, and 8% of Group C replied that their family purchased indoor footwear for them. This reminds us that we need to clearly know whether the person who purchased indoor footwear was the person who wore it before designing these products, services, and user experiences. This will affect the design of an effective and adaptive user experience from purchasing, wearing, to after-sale service with different target users in the journey, because we envision the tailor-made product and service design starting from identifying the right users in the journey across different key experience touchpoints.

3) Establish indoor footwear brand awareness and build trust in users.

In terms of people's preference for certain brands of indoor footwear, we found that 0% from Group A, 7% of Group B, and 29% of Group C had a brand preference for indoor footwear. See Figure 6.22. People's brand awareness of indoor footwear was relatively low compared with that of other types of shoes. This indicates the available business opportunities for new indoor footwear brands, specifically those targeting older adults. With such marketing potential and the vastness of users' unmet needs, we hypothesized this phenomenon could enable some footwear companies to create great tailor-made products combined with human-centered services and sustainable business models that cultivate customer loyalty and trust. We assumed that increasing people's awareness of the product brand might influence people's brand loyalty in the long run.

4) Improve people's attention to foot health across different generations.

In raising people's awareness of indoor footwear brands, we also realized the importance of raising the generations' attention to foot health over time. From the literature review, user interviews, and survey, we found that the majority of older adults were not aware of their foot health conditions or they had misconceptions about what they thought they knew about their foot health. Part of this gap in knowledge was attributed to a lack of educational exposure provided by the government and the medical system to teach people to take care of their foot health with the help of their family doctors, including how to select the right pair of shoes with the suitable measurement tools and expert diagnosis especially as people gradually become older.

Inevitably, people's feet will be gradually deformed and asymmetric when they become older, whereas our footwear design generally has not evolved or grown with people as affordable or accessible customized designs for such concerns are not available for most shoe components. This might make the price of shoes too expensive for people to purchase. As such, people need more professional guidance from doctors or caregivers regarding their foot health conditions.

Big footwear brands (e.g., NIKE and Adidas) sell footwear products along with their services to the general public, but they do not specifically provide foot health services to advise, diagnose or track older adults' foot health. This could include improving the wearing experience and comfort level, and integrating tailor-made shoe components that may need ongoing modification or replacement.

In conclusion, improving people's attention to their foot health is merely a first step. We also need to integrate the whole footwear design service system into enhancing the awareness of older adults, caregivers, designers, engineers, educators, medical practitioners, and other key stakeholders of the system to work together to better understand this issue. A further systemic challenge we need to consider is how we initiate and expand the awareness of footwear health and care for older adults, starting with the younger generation. The issue is more than touching upon people's foot health. It may start there but it seamlessly interconnects with government policies, the education system, and people's family culture, ife and work styles, and personal health conditions.

10.1.2. Product—Indoor Footwear Design for Older Adults

1) Raise people's awareness of the importance of product design combined with service components, In the study, we expanded the meaning of the term “product” into more than physical indoor footwear design. It also covered the service around the products to deliver a full user experience. In Figure 6.17., only approximately a quarter of participants showed interest in the concept of an indoor footwear service. For example, three groups including Group A (26%), Group B (28%), and Group C (22%) showed interest in having a correct professional measurement of their feet before purchasing indoor footwear. All three groups also showed desire to have a one-year after-sale service to keep their indoor footwear in good condition.

Many reasons affected people’s awareness of product services: customers’ educational background and knowledge of their foot health, whether footwear companies or brands offer product-related services, and more. From the research, we discovered many potential business opportunities for not only footwear companies or brands to build the indoor footwear product design, but also for people including older adults, their care providers, medical practitioners, and designers to participate in the design of human-centered service components.

2) Consider people’s data privacy, dignity, and ethics of product design and design process.

Instead of addressing indoor footwear product design with the state-of-the-art technologies from the functional aspect, designers and engineers need to think of the emotional experiences of older adults and their caregivers. Most IoT wearable product designs (e.g., smart watches and smart glasses) are created to use people’s data as “smart fuel” to keep the products evolving by understanding the users’ wearing behavior, patterns and and decision-making processes. Even though the majority of product experiences are seamless and easy for users, we need to consider the hidden side of this smart data.

Take indoor footwear design as an example. When designers and engineers build a new footwear product to monitor older adults’ health conditions through their indoor trajectory, walking pattern, speed, and other indicators, our intention is to design a responsive mechanism to ensure the safety of the users by notifying users, their families or medical team, whereas there is always tradeoff between privacy and safety for designers and engineers to create products and services that not only maintain the feasibility of the product, but also make users feel comfortable and safe with dignity.

How does smart indoor footwear protect users’ data privacy by storing people’s data on the device either locally or in the cloud? In addition to considering designing with dignity and ethics, we need to modify designers’ biased mindsets in the process of creating products for older adults. To establish a respectful and meaningful interaction through indoor footwear products, services, and experiences, what are the suitable conditions and design criteria that designers or engineers need to be aware of?

People’s data privacy, dignity, and ethics of product design are not just a slogan or only something that stays at the strategic level on paper. Instead, we need to re-consider the user’s emotional aspect and user experience by integrating the lens of social, justice, and ethics into further product design and development.

3) Review the cultural angle by integrating it into the product design development process.

When we interviewed people wearing indoor footwear at home, the most direct and frequent feedback we received was "We don't take off shoes and put on slippers at home." Unsurprisingly, our interviewees were from various countries, backgrounds and cultures. Wearing indoor footwear or slippers might be more common in Asian countries compared with Western cultures. This suggests a need to think of people's mental perceptions to define indoor or outdoor space in their house.

Whether or not people wear indoor footwear at home is one example to show cultural differences and personal habits. For the long-term goal, we have to consider the product design and development process inclusively by discussing different modules and features of the product and service design to comprehensively address and satisfy users' pain points and desires with diverse cultural backgrounds, religions, rituals, languages, and even policies. This is a critical point that not only creates business-wide opportunities and success for better sales, but also demonstrates the essence of using HCSD that we always put people in the center of the design and design process.

4) Translate people's trajectory and behavioral data into human-centered criteria for environmental and spatial design.

The beauty of the innovative indoor footwear product and service design is that we can fully leverage people's indoor trajectory and behavioral data to help us rethink their environmental and spatial design by applying HCSD and data.

In the future, how do we design an algorithm or AI to translate older adults' indoor traces, number of footsteps, walking speed, frequency of entering/leaving a certain space, and other critical behavioral data (e.g., health conditions, fall detection) into a series of tailor-made space design principles and suggestions to help them renovate their environment to not only optimize their space usage, but also make their space meaningful and delightful based on their tastes, personal habits, and life rituals?

Once we can analyze and translate people's behavioral data into business potential, it will help us synthesize the data and map out the information to re-envision people's space design. It can also help us make science-based suggestions on how to renovate people's space in the future based on their behavior, rather than on just aesthetics or architects' taste.

10.1.3. Platform—Service Innovation and Experience Design

In addition to focusing on indoor footwear product design, we also considered the service component and user experience design around the product. Our goal is to provide older adults with a sustainable and user-friendly indoor footwear solution covering the levels of product, services, and experiences.

The storyboard of 28 frames from Section 8.2.1., combined with the survey and interview results from experts and users, illustrate more accurate user journeys with three different scenarios: 1) one person at home, 2) a couple at home, and 3) more than two people at home. It led us to consider key touchpoints centered on users' needs including pre-purchasing indoor footwear, purchasing indoor footwear, after-sale service, and medical consultation services, and think of raising awareness of foot health and education for older adults and expanding it across different generations.

One goal is to support the indoor footwear service design and user experience by using HCSD methodology and framework. Therefore we viewed the indoor footwear product as a system innovation project.

Meanwhile, before establishing any new products, services, or platform systems, we need to consider carefully the consequences of creating new IoT products, especially in the context of the global environment. We only have one earth and we need to be mindful of each decision we make. The holistic thinking to view ideas from different aspects will help us build a better, robust, and inclusive system platform.

1) Design product systems more than products.

Typically, most designs and researches focus on how to design better quality indoor footwear for people (and few target older adults), but it is uncommon to see the footwear brands or companies emphasize the importance of service design and user experience. The footwear brands or companies do provide limited customer service for their products e.g., a typical after-sale service by giving customers phone numbers, but what we are interested in and investing in is a product-and-service ecosystem, which calls for designers, engineers, and researchers equipped with broader perspectives for human-centered visions to come up with new ideas.

In the study, we want to offer platform-oriented solutions supporting the idea of providing a product-and-service ecosystem. Creating a pair of tailor-made footwear soles and shoes might be relatively easy to save the cost of investing time, labor, time design phase, manufacturing stage, product shipment, and other key factors by leveraging the advanced fabrication technologies and computational CADing software. But the integral question is how to identify our target users' unmet needs and address their pain points through human-centered design, technology, and science and embed these research insights and suggested solutions into the current footwear design and development of an inclusive system integrated with diagnostic medical services, tailor-made modular product components, and education offers to deliver a better user wearing experience and improve people's quality of life, especially for older adults as care recipients and for their caregivers and families.

To design a successful indoor footwear product, we need to consider the interaction with people, products, services, and experience within its system. For example, there is no centralized platform for IoT devices. Users might want to install a Nest thermostat, but if their existing heating system is a European spec at their home, that would conflict with Nest, which uses US specs. As a consumer purchasing IoT products, it is less about the product, and more about the issue of the cross-platform. IoT products rely on their ecosystem. In addition, we need to view the product design in a holistic way by considering the system and platform level as product design architects.

2) Shift from product-centered, platform-centerd solutions to people-centered systems.

We want to achieve system-oriented solutions as our ultimate goal, and designers, engineers, and researchers need to build people-centered systems. "Most IoT products don't improve the quality of life for people; instead, it increases the outcome of life to make people work more. IoT product design/industry is still in an infant stage. Most are still function-driven features by work efficiency improvement," said Tobias Toft, Creative Director at Google, which reminded us that current products on the market still need to improve the human/emotional side of product features and relevant services.

According to the expert pre-interview survey, 75.9% said they wished IoT wearable devices could make their life convenient (Figure 5.11.). The high percentage enabled us to consider why convenience mattered to them as experts or users. To help us build better people-centered products, services, and systems, we need to clearly know users' needs first, which resonated with what Jerome Goh, Design Lead at IDEO, Adjunct Assistant Professor at Newschool, shared with us during the interview. "Most current IoT smart products are designed for ease of use, and convenience. Objects make people's life easier. But what are people's real needs?"

Paul Hatch, Partner at TEAMS, helped us to elevate the concept of people-centered product and system design further by proposing three aspects: awareness, improvement, and mindfulness while designing smart IoT product services and experience for users.

3) Promote Emotional Intelligence (EI), the fuel of Artificial Intelligence (AI), to people-centered products and systems.

In our expert interview, one said, "The process of designing IoT products is not that different from other traditional product design development processes. What matters is the human value and human needs." We were using IoT products as an example that also reflects on the technology itself. "Technology is an enabler, and it is the key component in the toolkit, but it is not the reason why one is an engineer. The real driver is social, because engineers want to improve the quality of life out in the community," said Dr. Avenr Engel [109].

Another expert mentioned that most IoT product design and service ideas were actually inspired by users' laziness. Take turning a light on as an example. We know it is a simple action for a normal person. But what if people have an option to control the light button through their voice? What is the incentive to control with one's hand versus voice?

Some human-centered design solutions might be inspired by people's laziness. This is actually an obvious way for us to understand our target users to study their behavior either at work or in their lives.

When designers, engineers, scientists, or researchers discuss how to embed Artificial Intelligence (AI) into the indoor footwear product system, it highlights the importance of amplifying people's needs and values. As the idea of proposing Emotional Intelligence (EI) reminds us, during the product design and development process, the goal we need to achieve not only focuses on the functional aspect, but also considers the emotional angle to deliver the human-centered user experience covering products, services, and systems.

4) Design people-centered platform with data ethics enabling social responsibilities.

When we face social-technological challenges, we think about how technologies have gradually or dramatically transformed people's lives, work, and the way we communicate, especially during COVID-19. Due to advanced technologies and the Internet, everything around the globe is interconnected and relevant. Therefore, data has become significantly important as a currency of IoT products and technology to reshape our communication, thinking process, and communities.

In the expert interview, one expert (participant 28), Director of Global Design at an American multinational technology corporation shared with us that he thought data, as a straightforward material, could be a useful tool to inform designers and their design processes. But how were we to assure that the data was unbiased as designers?

Meanwhile, there is a broader ethical issue of capturing, using, and storing data that we need to be aware of. From our interviews with users and experts and research, we assumed that most users aren't equipped with enough knowledge regarding the data-ethics-related topics, which is the foundation of successfully integrating data into the design process. The balance between data, data ethics, and human connection has become increasingly critical and sensitive. HCD is about maintaining balance in every aspect to enable social responsibility. In the future, everyone should be mindful of and take care of the social responsibilities generated.

10.1.4. Process—Human-Centered System Design (HCSD)

The process section helps us not only to improve our indoor footwear design and research process in general, but also to refine the new framework of HCSD and its implementation for future studies.

1) Focusing on what users didn't say might matters more than what they said during interview process.

To help us better create a new process and refine the previous structure, we obtain one critical learning from the study: we need to pay attention to our interviewees, including older adults and industry experts, about what they didn't say instead of what they said in research.

Frequently during user interviews, surveys, and participatory workshops, we realized that there were open-ended questions for which survey participants didn't want to share their honest feedback because of possible privacy issues, or personal concerns, or because they didn't know how to articulate their suggestions. For example, participants shared that they wanted to have a comfortable pair of indoor footwear but they didn't explain further why comfortable footwear matters to them. Also the adjective “comfortable” is a broad and context-driven word for which everyone has their own interpretation. Therefore when we conduct user interviews, we need to pay attention to not only what they said, but also what people didn’t say.

We can also achieve better virtual interview results by considering the engagement section of each interview. Under normal circumstances, how might we improve the virtual interview experience for both interviewers and interviewees to generate high-quality results? Designing engaging sections in interviews mattered based on our experience in the study.

Thus, we created three interaction sections in each interview, including a 3-minute pre-interview survey serving as an ice-breaker, using a few Zoom polls during the interview to increase the level of engagement, and setting a rigid bio break during the transition between different topics within the 45-minute interview. The above three engaging sections were very helpful both for interviewees and facilitators because they helped us quickly identify discussion points according to the pre-interview survey, ease awkward silences in the interview, and build trust, all making the virtual conversation more constructive.

Lastly, we also thought about other formats to conduct remote interviews with our users and experts. We understood that there were many other approaches to conducting virtual interviews. Besides video calls, e.g., Zoom calls or Google Meet, we considered that traditional ways like phone calls might also be effective and direct, especially for older adults, most of whom have severe hearing loss issues. Further research can explore whether video calling might contain a visual distraction. Through audio communication, interviewees and facilitators might pay more attention to the content of their conversations.

2) Leverage the benefit of rapid prototyping: iterative fast-paced process at a low cost.

The seven inclusive footwear design models and one computational footwear sole prototype constructively help us polish some of the early design concepts inspired by the literature review, survey and interviews with users and experts, and participatory workshops.

Prototyping is a fast and interactive process, which can help designers and engineers efficiently test potential design ideas in low resolution before the companies make huge investments in the manufacturing process. The sooner we tested our design, the more quickly we identified the problems at a relatively low cost.

In the study, we emphasized prototyping for early-stage concepts. For example, in Table 6.6., we visualized ten different indoor footwear concepts to quickly probe the interest level of the older adults. Our intention was to understand whether these concepts met older adults’ expectations to address their pain points and how they could help us refine the ideas effectively and efficiently. Due to the three-year scope of the project, we didn’t include a manufacturing plan for indoor footwear design. Instead, we can take indoor footwear manufacturing into consideration for future studies.

3) Infuse computational thinking and data analysis into the design process.

In Section 9.2., we prototyped seven inclusive footwear design models and experimented with footwear soles by using a field-driven approach. We had already conducted user research to understand people's needs as a great transition into the design/execution mode. This might be a critical step that most people overlook before jumping into the design. Regardless of using an inclusive design or a computational approach, HCSD is the framework for understanding people's needs as a priority.

Assuming that when we integrated users' behavioral data (e.g, indoor trajectory trace, health condition information) and computation feature with designers' experiences and intuition, our HCSD design process would become not only powerful in terms of accuracy (e.g., expected test results, project deliverables) and efficiency (e.g., response time, labor cost) but also meaningful to reflect people's needs, which realized the ideal design outcome. We acknowledged that there were still many components we needed to test to validate this assumption.

In Chapter 9, we discussed the design outcomes from the seven inclusive design models and computational footwear sole prototype to reflect our current design process and the possibility of combination with HCSD. Understanding users' desires by clarifying older adults' needs (Chapter 6) is the top priority that can ensure this creative experiment is more likely to be successful.

However, we had an idea to infuse computational thinking and data analysis into the HCSD design process. We were also curious to discuss the connection between HCSD, computational thinking, e.g., the field-driven approach and data analysis, and how we can integrate or curate them reasonably. In dealing with data-related problems in particular, although we know how to capture data from our target users, e.g., older adults, we also need to learn how to make sense of data from users' perspectives or key stakeholders' angles where this could be an entry point for applying HCSD.

4) Keep perspectives while managing the converging and diverging design processes.

In Chapter 7, we conducted two rounds of hybrid participatory workshops, since the pandemic has greatly transformed the way we work and live, especially in terms of conducting a hybrid participatory workshop. Our intention was to not only gather more comprehensive suggestions, but also to involve our participants as part of the design process to make it inclusive, transparent, and diverse.

We considered the following questions: How do we design an engaging workshop experience either in-person or with virtual participants to make them feel safe, welcome, and open-minded to contribute their ideas? How do we develop a series of toolkits or props to help us better facilitate hybrid workshops that create a positive and creative vibe? How do we make collective decisions while maintaining our opinion during/after the hybrid workshop? These reflective questions inspired us to reexamine the HCD process. There is still much room left for integrating the digital touchpoint and engagement sections within the design thinking process.

Instead of conducting traditional user/expert interviews or surveys, participatory workshops were used as an experimental approach to do the research. It also built a mutual communication channel considering team dynamics, discussion flow, co-working, and co-creation sections. Therefore, it posed a potential challenge for us: how to manage converging and diverging design processes collectively without losing perspectives.

One key benefit of hybrid participatory workshops was making a typical design process more transparent, inclusive, and diverse. In the study, our workshop topic was to envision the future footwear for older adults, and the brainstorming session was an important input before investing in the actual indoor footwear product design, because these inclusive and diverse responses indeed gave us more holistic views on our target users: older adults from their lifestyle, ritual, personal hobbies, health condition, homes, and relationships with their family members.

OpenIDEO, an online interactive collaboration platform, is a great example that invites participants around the globe to ideate, reframe, prototype, and solve some of the most difficult, complicated, systemic, social-technological challenges with companies or governments. Participants get support to make an invaluable impact on complicated social-technological issues, connect with many innovators across the globe, train and build their skills by applying design thinking approaches, and access the right resources to help make actionable plans.

We also explored creating a hybrid platform with a series of toolkits and methodologies to empower participants to contribute their ideas in a democratic way. For example, when we collaborated on a virtual workshop with -ing Creatives, we prepared a workbook for the participants to download and print in advance for making paper prototypes of footwear design [143].

Another example was using a virtual Miro board paired with physical Post-it notes, which made the hybrid participatory workshop brainstorming phase more accessible for participating online and offline; by using a virtual Miro board properly, it was relatively easy to share content, ideas, and feedback, and keep the document organized afterward. It is a scalable approach for brainstorming that we hadn’t experienced before the pandemic.

Essentially, we want to conduct a hybrid conversational participatory workshop by making a space that allows for converging and diverging design processes while collecting various insights from the groups without losing the original ideas and creative perspectives.

5) Make and scale broader positive social impact by applying Hunan-Centered Design (HCD).

One critical challenge of applying HCD is how we scale the social impact by solving large complex systemic social-technological challenges, since we conducted user interviews and surveys or facilitated a series of participatory design thinking workshops as a traditional way to follow the HCD process. We were curious what other effective approaches were if we need to manage a large amount of data in a short time, and how we can apply HCD methodologies to adapt to different complex situations with reasonable timelines and resources?

These common problems are the bottlenecks that designers or people who use HCD will constantly face. Imagine if we need to prototype a space satellite by using HCD in a constrained time and with limited resources. Can we do it with the current HCD process? How much time and money do we need to invest if we just follow the traditional HCD process?

Therefore, in industries, some pioneering design-related creative agencies and companies have started to think of refining HCD or integrate some system thinking/design into the HCD process to solve these large, complicated social-technological challenges. IDEO has already provided some job positions, e.g., system designers or organization designers, to deal with the burning needs of organizations or industry transformation projects [122].

In fact, HCD is an invaluable design approach and has been applied across many disciplines: manufacturing, social science, sustainability issues, and more. HCD is also not a slogan. It is an actionable design process from inspiration, to ideation, to implementation with comprehensive consideration to find the sweet spot among people's desirability, business feasibility, and technology viability. We treat HCD not as a noun, but instead as a verb that can be applied to various social impactful challenges.

6) Aim to craft an ideal process of using Human-Centered System Design (HCSD)

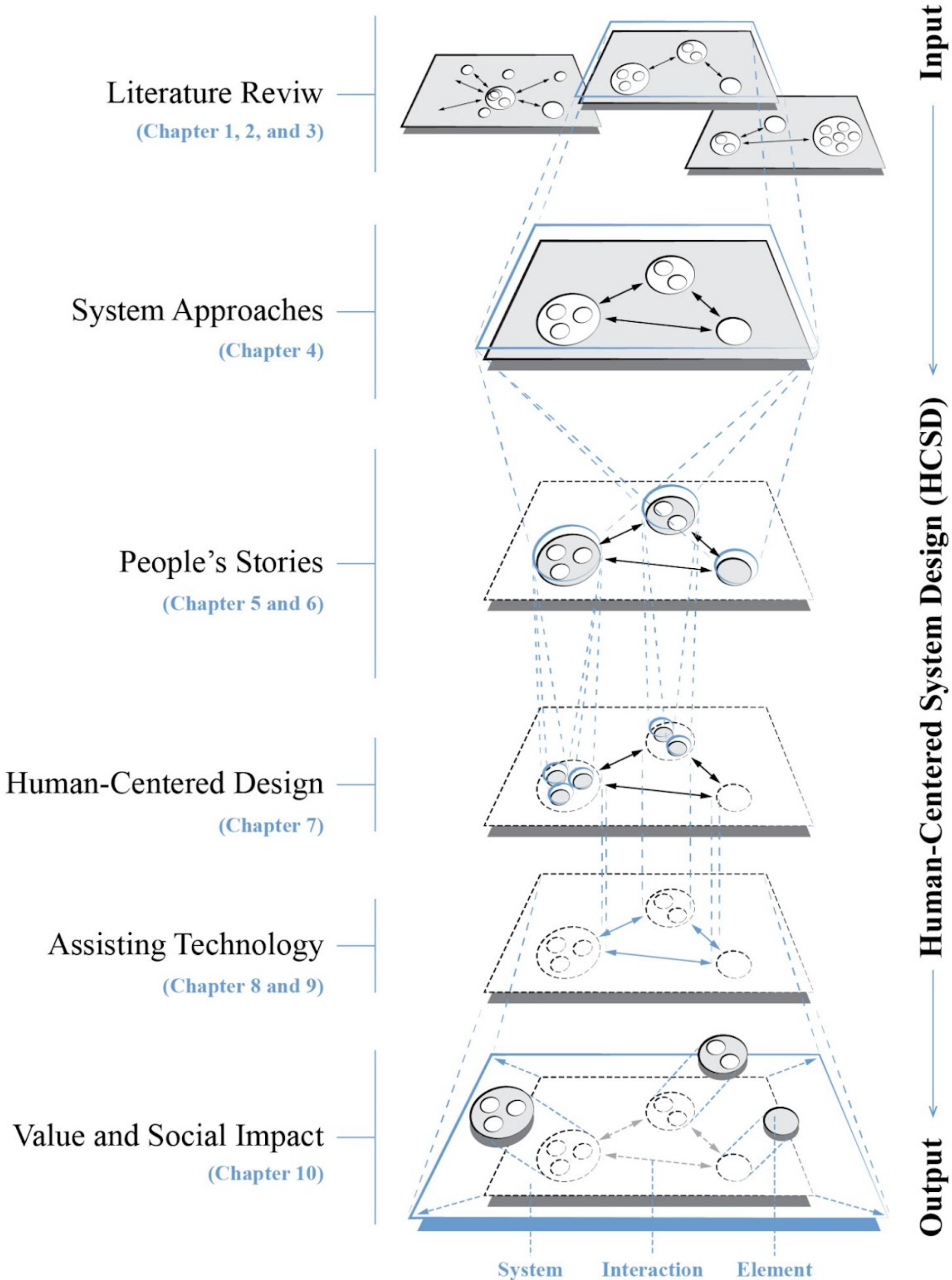
A better understanding of system approaches helps leverage the benefit of system approaches and integrate them into the HCD and DT processes. In the study, we researched the definitions and implementations of System Engineering (SE), System Architecture (SA), System Thinking (ST) and Human-Centered Design (HCD), and Design Thinking (DT) to get the whole picture of the proposed concept HCSD, and we tested three selected system approaches–OPM, ConOps, and DSM paired with HCD–to build a meaningful and impactful HCSD model.

For example, we experimentally combined OPM with a journey map to give each process link between objects a new meaning and brought a human-centered perspective into the system thinking. Another example was to add scenario design to each node of the phase in the ConOps to inform explicitly the who, where, and what. This minor change can efficiently help the project team identify the key stakeholders in the scenario, the situations they will be in, and the key challenges they will overcome.

Further studies can explore other system approaches besides OPM, ConOps, and DSM to merge with HCD or DT by demonstrating case studies to validate the concepts of HCSD. We found that there is no perfect system approach or design process. Thus we suggested HCSD as a context-driven framework strongly influenced by the types of challenges that designers, engineers, or researchers are going to solve.

Realistically, we cannot create a universal HCSD to solve any systemic and complex problem. It closely depends on which types of challenges we are going to solve, e.g., social impact projects, product innovation projects, or service-and-experience projects. And then we can identify which parts of the HCSD framework and methodology to use intentionally.

Figure 10.3. Master thesis project research flow (simplified version)
(illustrated by Sheng-Hung Lee and the diagram was part of Figure 1.3.)



10.2. Further Study

In addition to the four research opportunity areas in Figure 10.2., future research must explore the possibilities of innovating HCSD methodology and its potential applications to make more impactful social-technological innovation. This is discussed in Section 10.2.1. Other opportunities for design value and future research of indoor footwear design for older adults are highlighted in Section 10.2.2.

- Opportunity Area 1—the overlap between people and product
  How might we design indoor footwear products, service, and experience for older adults to address their unmet needs and improve their quality of life?

- Opportunity Area 2—the overlap between product and platform
  How might we build indoor footwear product systems for older adults to enhance human-centered services and seamless user experiences?

- Opportunity Area 3—the overlap between platform and process
  How might we establish Human-Centered System Design (HCSD) frameworks and methodologies to solve transformative social-technological systemic challenges?

- Opportunity Area 4—the overlap between process and people
  How might we shape and cultivate our future creative talents to help them acquire hardcore skills and human skills to adapt to the era of transformation with systemic challenges?

10.2.1. Academic and Methodological Applications

1) Experiment Human-Centered System Design (HCSD) by curating different SE and HCD.

We proposed HCSD frameworks and methodologies and applied HCSD to indoor footwear design for older adults as a case study to discuss the pros and cons not only of methodology refinement, but also of indoor footwear product, service, and experience innovation.

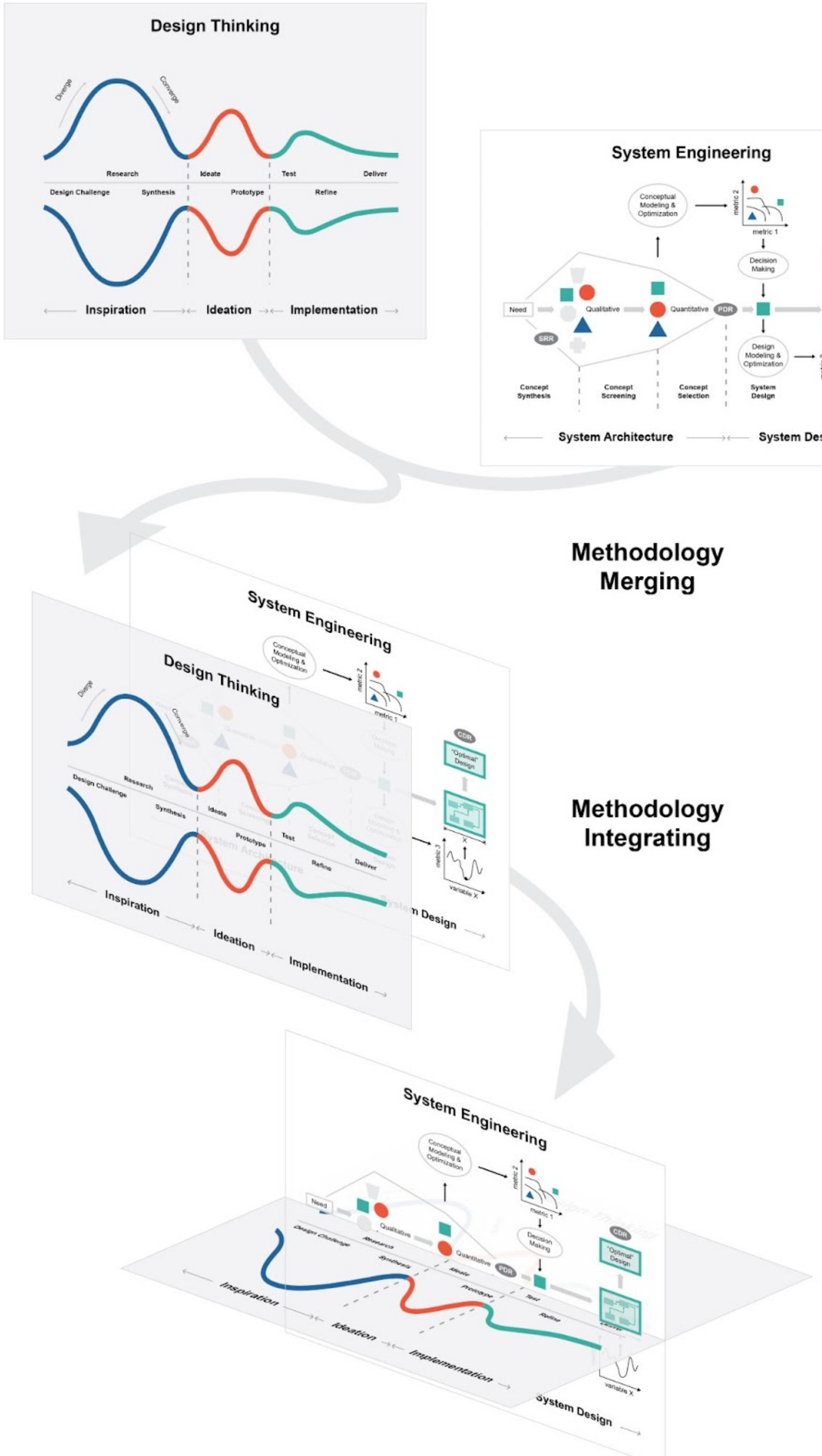
In Chapter 4, we discussed the application of OPM, ConOps, and DSM by experimentally merging them with user journey and design scenario from HCD and DT methodologies. There are other commonly used SE approaches worth investing time in and testing with different HCD and DT methodologies to refine the HCSD framework. We need to find some common ground to combine and use examples to prototype and justify merging different methodologies.

Figure 10.4. demonstrates one visualization of how we conduct experiments with different approaches to merge and integrate DT, HCD, and SE methodologies, but there are more

details than shown in the image that we need to consider. We suggested the following five questions:

1. Why do we need to merge two or more different approaches from different domains of knowledge? Will it make it more complicated to learn and apply to solve problems?
2. How do we set up the evaluation matrix/tools to measure the success of problem-solving by using HCSD frameworks?
3. How do we set up the right conditions for people, projects, processes, and platforms to use HCSD successfully to open up something socially powerful, beautiful, and magical?
4. What is the suitable format to demonstrate the value of using HCSD to solve systemic and complicated social-technological challenges?
5. In relation to key stakeholders in different types of complex projects, who are the right people to learn HCSD approaches beyond designers and engineers?

Figure 10.4. Experiment with the possible approaches to merge and integrate DT, HCD and SE approaches. (adapted from the published conference paper [4])



2) Explore the potential and types of projects by applying HCSD.

In the study, we focused on indoor footwear product design for older adults, covering the aspect of the product, service, and experience design. In addition to footwear product innovation, we can think about other types of design challenges or challenges in general: social-impactful projects, experience-oriented projects, and more diverse topics to test out and refine HCSD methodologies. Testing various types of complex, systemic projects in future studies can help us more effectively use HCSD in different stages of the creative process, and then explore the possibilities of applying HCSD as a critical design tool for social transformation [164].

3) Develop computational design process.

We learned and tested how a computational design approach can effectively decrease the cost of product design and development, especially for the tailor-made manufacturing process (Table 9.2.). As a next step, we can put more emphasis on developing a set of computational design methodologies to quantify the percentage of cost that can be reduced and to think of how to combine them with HCSD to make this proposed framework more impactful and adaptive.

10.2.2. Practical and Managerial Considerations

1) Expanded demographics of users and experts and research methodologies.

Due to the pandemic, we tested our samples in Boston, Massachusetts, United States of America, and in Taipei, Taiwan and we conducted the majority of the study's methods online. The scope of this project, time and budget limitations, and the partner laboratories' resources only allowed us to recruit target users from these locations. For more comprehensive and accurate results, we might re-scope the demographics of our users and experts' interviews and surveys to establish a collection of data for further studies.

Besides dividing our target users by age ranges, we can also think about different regions, countries, cultures, or rituals to analyze the varieties of senior lifestyles across the globe. This might also help us reexamine the recruiting criteria for inclusion of older adults in this study.

Another interesting research topic is how we conduct research and interviews with older adults. Especially during the pandemic, most communication shifted to online. Therefore, older adults might need to learn how to use such virtual meeting software (e.g., Zoom), to connect with people in general, not just for research purposes.

From the research experience with MIT AgeLab 85^{+} Lifestyle Leaders Panel, we understood that some older adult participants have hearing issues, which made us reflect that a video interview or phone call was probably the most appropriate way to conduct an interview. We thought about turning on the subtitles or asking someone to type the subtitles during the interview to help the interviewee read and listen at the same time.

Research with older adults enabled us to explore suitable approaches to conducting interviews with older adults to show respect and follow appropriate research ethics. In this study, we conducted standard virtual interviews and online surveys, but we haven't experimentally tested other innovative ways to study the aging population. This adds academic value in terms of research methodologies with older adults to make it inclusive and meaningful.

2) Design indoor footwear across ages to make inclusive solutions universal.

If viewing older adults as a type of "extreme" users on the spectrum, the opposite of babies, we use the word "extreme" to emphasize that people's physical and cognitive conditions are different. Therefore, when we design indoor footwear for older adults, we need to consider holistically many aspects of different in-home situations to meet the requirements of people's desirability, technology feasibility, and business viability. Specifically, being empathetic about older adults' pain points through in-person observation and field research can help us effectively address their unmet needs to better understand and solve the problems. This made us think carefully about other potential user groups on the same spectrum, since designing a great pair of indoor footwear can benefit many people, not only older adults.

While celebrating the idea of designing for older adults in the study, we can also experimentally expand part of our design solutions to the general public to embrace the inclusiveness of design philosophies and principles by adapting and transforming the typical creative process to become universal solutions [165]. According to the Inclusive Design Research Centre (IDRC), the idea of inclusive design is to consider the full range of human diversity with respect to ability, language, culture, gender, age, and other forms of human difference [166].

We envisioned an ideal environment full of universal considerations that echoed what Alessandra Pomarico described in her article [167], Situating Us where humans can celebrate their stories, bring their journeys and tools to the service of an emerging collective, a community of makers, involved in establishing an alternative, more just and ecological place.

In future solutions, we think of creating inclusive indoor footwear products that are not only designed for older adults, but also fit people of different ages. We recognized that there will not be a perfect design to meet everyone's needs, but we think that distilling inclusive design principles can empower designers, engineers, and researchers to come up with more structural and meaningful design solutions.

10.2.3. Roadmap of 4Ps Perspectives

Table 10.1. shows a suggested ideal roadmap of 4Ps perspectives (Figure 10.2.) to transition from the status quo. We identify the current conditions in academia and industries and examine future considerations: what we suggest can happen according to this research. We want to continue this future research to analyze the study through the lens of people, product, platform, and process to provide comprehensive suggestions.

Table 10.1. The roadmap of the 4Ps perspectives analyzed in the present study

	Transition	
4Ps perspectives	**Status Quo** Current conditions in academics and industries.	**Future Considerations** What we suggest can happen according to this research.
PEOPLE People-Centered Focus and Research	Define and clarify the target users' pain points, desires, unmet needs, and design opportunities within older adult groups.	How do we expand our target users from older adults to the general public, find their common needs and address their pain points?
PRODUCT Indoor Footwear Design for Older Adults	Build indoor footwear products with identifiable labels or indications that the products are designed for older adults.	How do we shift from creating indoor footwear products specifically designed for older adults to providing inclusive design solutions that are tailor-made for users with various health conditions and needs?
PLATFORM Service Innovation and Experience Design	Offer a limited and typical after-sale service and user experience around the indoor footwear product.	How do we shift from the focus on designing human-centered products to designing humanity-centered services and experiences around products?
PROCESS Human-Centered System Design	Use a typical design process or system thinking approach to do traditional product design and development.	How do we apply Human-Centered System Design (HCSD) to solve complicated and systemic social-technological challenges?

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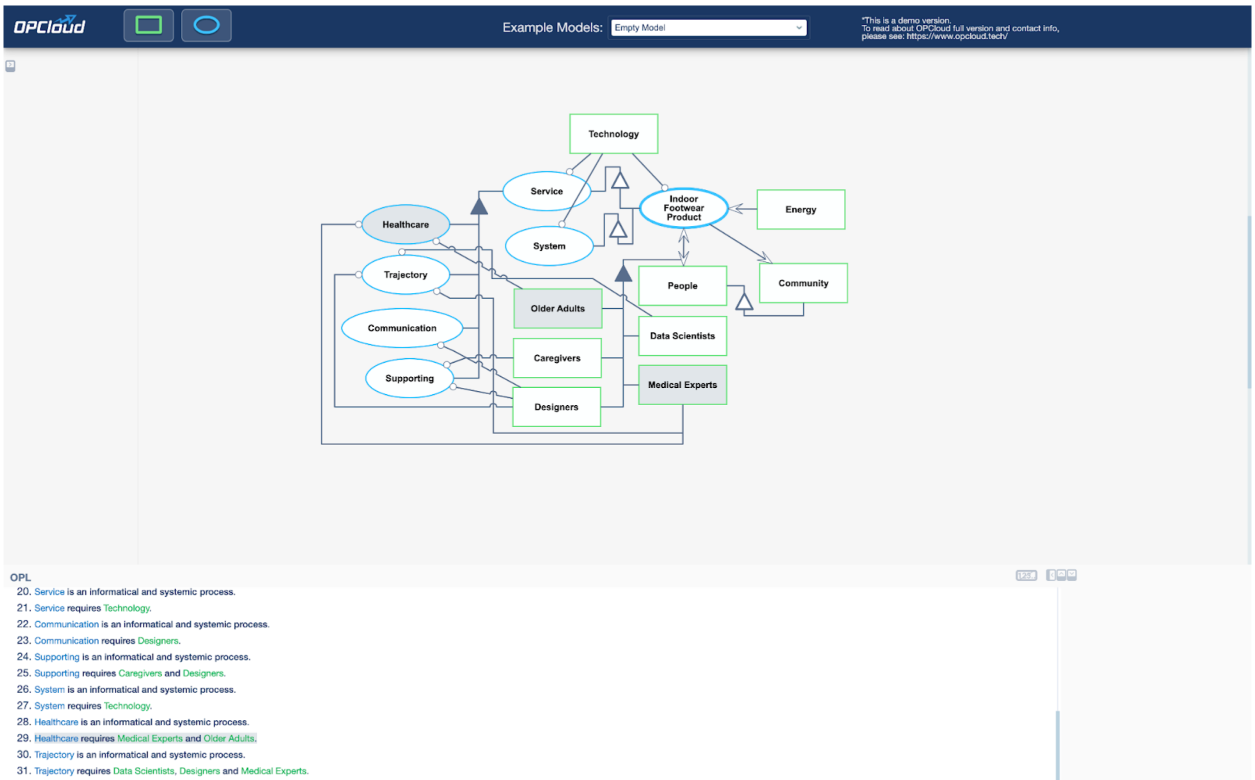
Appendix A—OPL

OPCloud will also automatically generate the OPM language, OPL, to help us understand the relationship between object-to-object or object-to-process or process-to-process by using different types of links e.g., generating, consuming, and attracting (Table 2.1.).

Figure A.1. The gray part in the OPCloud interface shows the connection and meaning between the 1st layer of SD and OPL. (the screenshot from OPCloud)

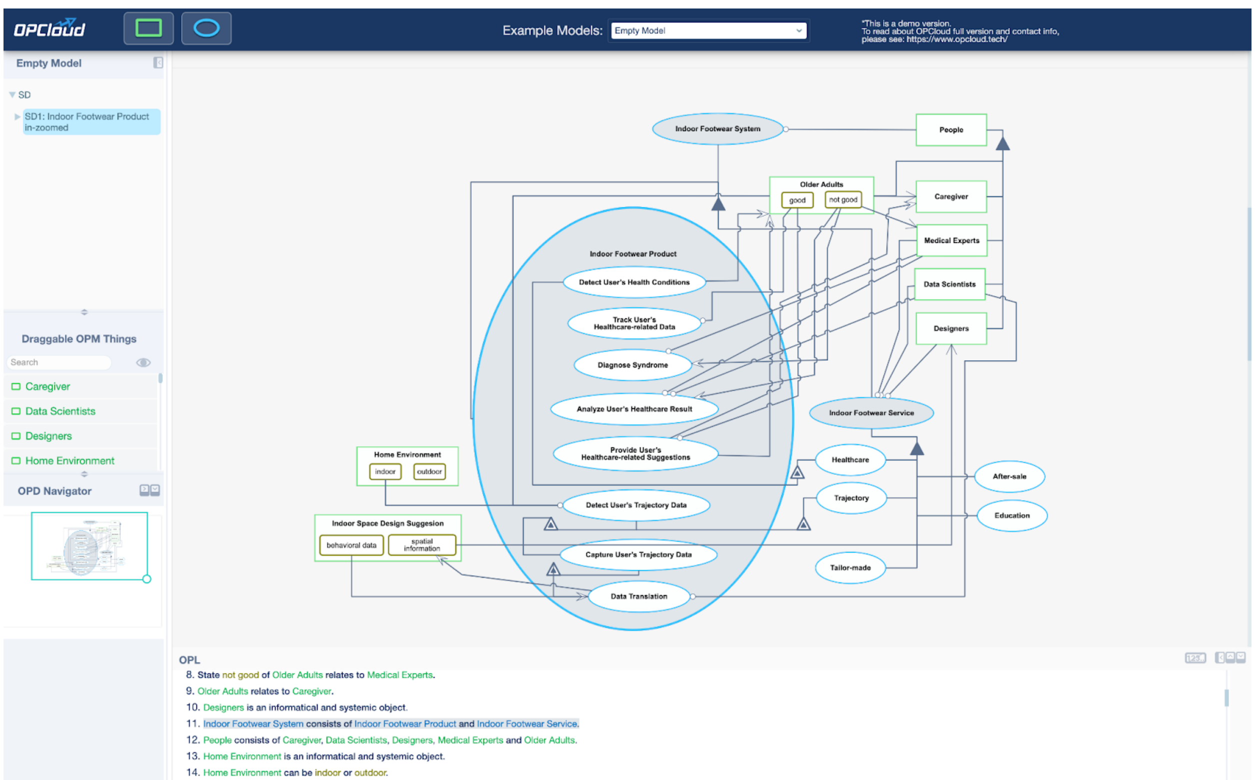


OPL of the first layer of SD (Figure 4.4.)

1. People is an informatical and systemic object.
2. Energy is an informatical and systemic object.
3. Community is an informatical and systemic object.
4. Technology is an informatical and systemic object.
5. Medical Experts is an informatical and systemic object.
6. Designers is an informatical and systemic object.
7. Older Adults is an informatical and systemic object.
8. Data Scientists is an informatical and systemic object.
9. Caregivers is an informatical and systemic object.
10. Indoor Footwear Product is Service.
11. Community is a People.
12. Indoor Footwear Product is System.
13. Service consists of Communication, Healthcare, Supporting and Trajectory.

14. People consists of Caregivers, Data Scientists, Designers, Medical Experts and Older Adults.
15. Indoor Footwear Product is an informatical and systemic process.
16. Indoor Footwear Product requires Technology.
17. Indoor Footwear Product affects People.
18. Indoor Footwear Product consumes Energy.
19. Indoor Footwear Product yields Community.
20. Service is an informatical and systemic process.
21. Service requires Technology.
22. Communication is an informatical and systemic process.
23. Communication requires Designers.
24. Supporting is an informatical and systemic process.
25. Supporting requires Caregivers and Designers.
26. System is an informatical and systemic process.
27. System requires Technology.
28. Healthcare is an informatical and systemic process..
29. Healthcare requires Medical Experts and Older Adults.
30. Trajectory is an informatical and systemic process.
31. Trajectory requires Data Scientists, Designers and Medical Experts.

Figure A.2. The gray part in the OPCloud interface shows the connection and meaning between the 2nd layer of SD and OPL. (the screenshot from OPCloud)



OPL of the second layer of SD (Figure 4.5.)

1. Indoor Footwear Product from SD zooms in SD1 into Detect User’s Health Conditions of Healthcare, Track User’s Healthcare-related Data, Diagnose Syndrome, Analyze User’s Healthcare Result, Provide User’s Healthcare-related Suggestions, Detect User's Trajectory Data of Capture User's Trajectory Data and Trajectory, Capture User's Trajectory Data of Data Translation, and Data Translation, which occur in that time sequence.
2. People is an informatical and systemic object.
3. Medical Experts is an informatical and systemic object.
4. Caregivers is an informatical and systemic object.
5. Older Adults is an informatical and systemic object.
6. Older Adults can be good or not good.
7. Data Scientists is an informatical and systemic object.
8. Designers is an informatical and systemic object.
9. Home Environment is an informatical and systemic object.
10. Home Environment can be indoor or outdoor.
11. Indoor Space Design Suggesion is an informatical and systemic object.
12. Indoor Space Design Suggesion can be behavioral data or spatial information.
13. State not good of Older Adults relates to Medical Experts.
14. Older Adults relates to Caregivers.
15. Indoor Footwear System consists of Indoor Footwear Product and Indoor Footwear Service.
16. People consists of Caregivers, Data Scientists, Designers, Medical Experts and Older Adults.
17. Indoor Footwear Service consists of After-sale, Education, Healthcare, Tailor-made and Trajectory.
18. Trajectory exhibits Detect User's Trajectory Data.
19. Healthcare exhibits Detect User’s Health Conditions.
20. State spatial information of Indoor Space Design Suggesion relates to Designers.
21. Capture User's Trajectory Data exhibits Detect User's Trajectory Data.
22. Data Translation exhibits Capture User's Trajectory Data.
23. Indoor Footwear Product is an informatical and systemic process.
24. Indoor Footwear Service is an informatical and systemic process.
25. Indoor Footwear Service requires Data Scientists, Designers and Medical Experts.
26. Indoor Footwear System is an informatical and systemic process.
27. Indoor Footwear System requires People.
28. Healthcare is an informatical and systemic process.
29. Trajectory is an informatical and systemic process.
30. After-sale is an informatical and systemic process.
31. Education is an informatical and systemic process.
32. Tailor-made is an informatical and systemic process.
33. Detect User’s Health Conditions of Healthcare is an informatical and systemic process.
34. Track User’s Healthcare-related Data is an informatical and systemic process.
35. Track User’s Healthcare-related Data requires Older Adults at state good.
36. Diagnose Syndrome is an informatical and systemic process.
37. Diagnose Syndrome requires Medical Experts.
38. Diagnose Syndrome consumes Older Adults at state not good.
39. Analyze User’s Healthcare Result is an informatical and systemic process.
40. Analyze User’s Healthcare Result requires Data Scientists and Medical Experts.
41. Analyze User’s Healthcare Result consumes Older Adults at state not good.
42. Provide User’s Healthcare-related Suggestions is an informatical and systemic process.
43. Provide User’s Healthcare-related Suggestions requires Older Adults at state good.
44. Provide User’s Healthcare-related Suggestions yields Caregivers.

45. Detect User's Trajectory Data of Capture User's Trajectory Data and Trajectory is an informatical and systemic process.
46. Detect User's Trajectory Data of Capture User's Trajectory Data and Trajectory requires Older Adults and Home Environment at state indoor.
47. Capture User's Trajectory Data of Data Translation is an informatical and systemic process.
48. Data Translation is an informatical and systemic process.
49. Data Translation changes Indoor Space Design Suggesion from behavioral data to spatial information.
50. Data Translation requires Data Scientists.
51. Exactly one of Detect User’s Health Conditions of Healthcare and Provide User’s Healthcare-related Suggestions yields Older Adults

Appendix B—Expert Interview Consent Form

CONSENT TO PARTICIPATE IN INTERVIEW

A Research Project about In-home IoT Product Design and Its Service

You have been asked to participate in a research study conducted by Sheng-Hung Lee from Integrated Design & Management (IDM) and Department of Mechanical Engineering and Ziyuan Zhu from Architecture at the Massachusetts Institute of Technology (M.I.T.). The purpose of the study is to understand people's behavior at home, their use of in-home IoT products and services as well as to study people's product experience and their ideas about the future application of in-home IoT products. The results of this study will be included in Sheng-Hung Lee's and Ziyuan Zhu's masters theses and academic publications. You were selected as a possible participant in this study because we consider that you are the potential target user of the research topic. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. We expect that the virtual interview will take about 30~45mins (30 mins interview and 15 mins for warm up and wrap up the conversation).
- We do not anticipate any significant risk to you from taking part in this research. You do not have to answer any questions you do not wish to or share any information with the group that you do not wish to. You may not receive any direct benefit from participating in this research, although you may benefit from having an opportunity to share your experiences with researcher and designer, and to suggest ideas and ways to improve design of future in-home IoT product and its service to create a better human-centered experience at home.
- You will not be compensated for this interview.
- Unless you give us permission to use your name, title, photos, videos and/or quote you in any publications that may result from this research, the information you tell us will be confidential.
- We would like to record this interview so that we can use it for reference while proceeding with this study. We will not record this interview without your permission. If you do grant permission for this conversation to be recorded, you have the right to revoke recording permission and/or end the interview at any time.

This project (research part) will be completed by the end of 2020. All interview recordings will be stored in a secure password-protected work space / server.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. In addition, your information may be reviewed by authorized MIT representatives to ensure compliance with MIT policies and procedures.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

(Please check all that apply)

☐ I give permission for this interview to be recorded.

☐ I give permission for the following information to be included in publications resulting from this study:

☐ my name	☐ job title and brief info	☐ quotes from this interview
☐ photographs	☐ audio recordings	☐ video recordings

Name of Subject

Signature of Subject ______________________________________ Date ____________

Please contact Sheng-Hung Lee (phone: 6173357115; email: shdesign@mit.edu) with any questions or concerns.

If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143b, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253-6787.

Appendix C—Expert Interview Discussion Guide

A. Platform Level—design and scenario

- Have you purchased or owned any in-home IoT product for yourself? Do you have one in your office? Why do you want to purchase it? How do you like it in terms of function, usability, design, CMF, cost, and other reasons?
- What in-home scenarios do you think to have the huge business potentials for IoT products with the indoor-positioning function in the future?

B. Product Level—design and data

- What do you think about the idea/concept “Design with Data”?
- If in-home IoT products can capture your behavioral data such as Alexa, Siri. How do you feel? What's your concern? Do you think personal information is shareable? What are the shareable information that can and want to share with the public?

C. People Level—design and behavior

- What types of in-home behavioral data you think are critical to you? Why do you think is important to you in terms of tracking your health condition, business value, potential implication, or other aspects?
- Please share with us your insight and learning about in-home IoT products e.g. its definition, product development, industry transformation. Do you have any particular experience or story about in-home IoT product with the indoor-positioning function?

Appendix D—Expert Interview Pre-survey

Question 1.

Your Name: ____

Question 2.

What comes to your mind when we mention "Smart Home"? (2~3 keywords)

____

Question 3.

How smart of IoT wearable devices do you feel comfortable to have (level of automation)?

	1	2	3	4	5	
The device needs to be set up before people use it. It follows the fixed program.	○	○	○	○	○	The device treats me as my close friends that understand and can predict my next step.

Question 4.

How comfortable you are if IoT wearable device can share your data on the cloud?

	1	2	3	4	5	
The device won't store any of my personal data.	○	○	○	○	○	I am willing to share my data on the cloud with the community.

Question 5.

Design with data is (please complete the sentence)

____

Question 6.
If you have a pair of smart slippers, what kind of functions do you want to have? (multiple choice)

- ☐ Help people do exercise
- ☐ Detect health condition
- ☐ Control home appliance
- ☐ Communicate with people
- ☐ Track in-home trajectory
- ☐ Serve as an assistant
- ☐ Make people relax
- ☐ Other

Question 7.
You wish IoT wearable devices can help you (multiple choice)

- ☐ Improve work efficiency
- ☐ Increase creativity
- ☐ Optimize time
- ☐ Make life convenient
- ☐ Connect people
- ☐ Other

Appendix E—Expert Interview Notes

We didn't cover the complete expert interview notes. We documented selected expert interviews that inspired the research with their key quotes.

Table E.1. Key quotes from expert interviews

Expert	Interviewee Name	Key Quotes
1	Craig Mackiewicz	For my understanding, most IoT products are designed to focus on people's convenience and how it benefits people but not putting their security at risk.
2	Giovanni Di Vaio	At home, I will keep moving things, furniture around. It influences my mood and inspiration. I will also think about the experience of my guest while I invite them to sit in different corners at home.
3	Participant 3	I want every smart IoT device in my home to be seamlessly connected and they can have the conversation so that I don't even need to bring and use my phone at home.
4	Michael Abcunas	When I choose IoT products, I consider three aspects: 1. Efficiency— It can make my life convenient; 2. The pace of my life—It can help me control my life pace; 3. Cost—This is the least critical one since every product has its price.
5	Lionel Wodecki	Every time I will consider the consequences if I need to create a new IoT device. We need to think about the issue in the context of the global environment since we only have one earth.
6	Tobias Toft	Most IoT products don't improve the quality of life for people; instead, they increase the outcome of life to make people work more. That's why I feel bored with them. IoT product design/industry is still in an infant stage. Most are still function-driven increasing work efficiency.
7	Jason Belaire	IoT products can easily predict people's daily behavior, movement, and trajectory, but it's hard to read what's on people's minds. The time of "I know what you think" has not yet come.
8	Jerome Goh	Most people know they should protect their data, but the truth is the boat (data security) sailed a long time ago. People are just trying to protect data, but it is actually out of control already.

Table E.1. Key quotes from expert interviews (continuum)

Expert	Interviewee Name	Key Quotes
9	Paul Hatch	A successful IoT product won't mention it as an IoT product, since people won't purchase an extra coffee machine with sensors. Instead, designers need to reinvent the overall user experience when people use a coffee machine.
10	Participant 10	I only want my IoT product to show the things, the functions that you (product) promise and I don't want to have any surprises.
11	David Patton	Even though the future of the IoT industry is limitless with huge potential in its application and its service, IoT product doesn't mean it is smart and understands consumers' needs.
12	Sebastian Gier	Design with data is like a generative design. You don't know the actual outcome and it is unlike furniture design that designers can predict the result once they have an idea. Design with data normally could generate unpredictable results unexpectedly.
14	Participant 14	The IoT is a broad term that becomes almost a meaningless label because it can mean everything. The term "smart home" is definitely a cliche word. People recognize the term but don't understand its meaning.
15	Participant 15	I prefer to read the newspaper. I mean the physical one since it relatively won't filter out most information I dislike. In the digital world, the platforms like social media provide you with the information, video, WhatsApp you prefer to read. I am afraid that everyone will end up living in their own bubble without the need for communication.
16	Participant 16	What's missing for IoT devices is that there is no centralized platform. I want to install a Nest thermostat, but my existing heating system is a European spec, which conflicted with Nest. As a consumer purchasing IoT products, it is less about the product, but rather more about the cross-platform issue.
18	Taylor Goldy	Most consumers' imaginations are limited to TV or the things they've experienced, such as most smart features encapsulated in a watch. How to create something that is new yet they are already familiar with–such as items including slippers–in their mental model that combines with new smart features integrated into daily life?
22	Pedro Ferreira	From 0 to 100 is how my life changes with a smarter lifestyle. There are definitely trade-offs but I am excited to give it a try.

Appendix F—ARE Evaluation Result

Under each criterion: adaptability, expertise, and responsibility, its evaluated scores (from scores 1 to 5) were the average numbers given by two researchers who participated in 31 expert interviews based on our discussion with experts. ARE evaluation framework was a subjective way to measure each expert interview result, so we decided to even our scores.

Note: We didn't give the number to Jake Knapp's interview, because we didn't use the video call formate of conducting an expert interview. He shared with us his viewpoints through email according to our interview discussion guide and pre-interview survey.

Figure F.1. ARE evaluation result of 31 expert interviews (same as Figure 5.15.)

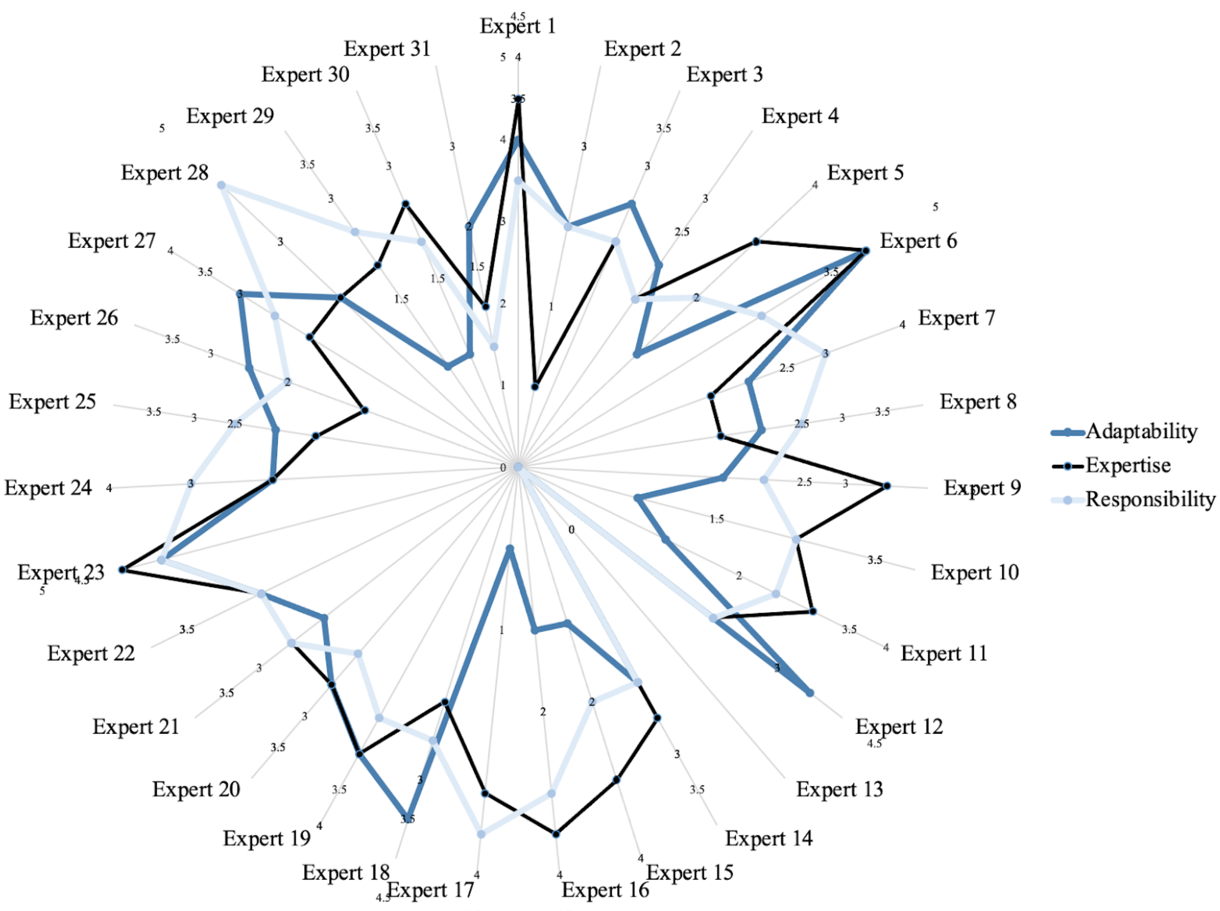


Table F.1. ARE evaluation result

		Adaptability			Expertise			Responsibility		
Expert	Interviewee Name	Researcher 1	Researcher 2	Average	Researcher 1	Researcher 2	Average	Researcher 1	Researcher 2	Average
1	Craig Mackiewicz	4	4	4	4	5	4.5	4	3	3.5
2	Giovanni Di Vaio	3	3	3	1	1	1	3	3	3
3	Participant 3	3	4	3.5	3	3	3	2	4	3
4	Michael Abcunas	3	3	3	2	3	2.5	2	3	2.5
5	Lionel Wodecki	2	/	2	4	/	4	3	/	3
6	Tobias Toft	5	5	5	5	5	5	3	4	3.5
7	Jason Belaire	3	3	3	3	2	2.5	4	4	4
8	Jerome Goh	3	3	3	3	2	2.5	3	4	3.5
9	Paul Hatch	3	2	2.5	5	4	4.5	3	3	3
10	Participant 10	2	1	1.5	3	4	3.5	4	3	3.5
11	David Patton	2	2	2	4	4	4	3	4	3.5
12	Sebastian Gier	4	5	4.5	3	3	3	3	3	3
13	Jake Knapp	/	/	/	/	/	/	/	/	/
14	Participant 14	3	3	3	4	3	3.5	3	3	3
15	Participant 15	2	2	2	4	4	4	3	3	3
16	Participant 16	2	2	2	5	4	4.5	5	3	4
17	Gordon Bruce	1	1	1	4	4	4	4	5	4.5
18	Taylor Goldy	4	5	4.5	3	3	3	4	3	3.5
19	Julian Bleecker	4	4	4	4	4	4	3	4	3.5
20	Sandeep Pahuja	4	3	3.5	4	3	3.5	3	3	3
21	Participant 21	3	3	3	3	4	3.5	4	3	3.5
22	Pedro Ferreira	4	3	3.5	4	3	3.5	4	3	3.5
23	Will Walker	4	5	4.5	5	5	5	4	5	4.5
24	Lorraine Justice	3	3	3	3	3	3	4	4	4
25	Participant 25	3	3	3	3	2	2.5	4	3	3.5
26	Amelia Juhl	4	3	3.5	2	2	2	3	3	3
27	Angie Kim	4	4	4	3	3	3	3	4	3.5
28	Participant 28	3	3	3	3	3	3	5	5	5
29	Michael Held	2	1	1.5	4	2	3	4	3	3.5
30	Bill McInnis	2	1	1.5	3	4	3.5	3	3	3
31	Alessio Grancini	3	3	3	3	4	3.5	3	3	3

Appendix G—User Survey Consent Form

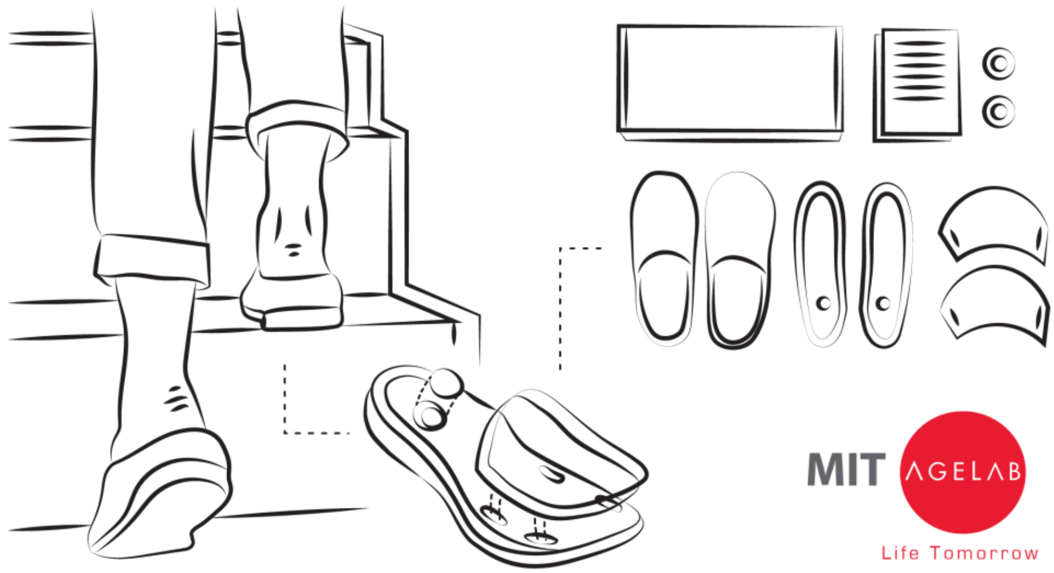
The user survey consent form was integrated into the user survey (part 2) in Appendix H—User Survey Design. All survey participants were required to finish the consent form before replying to the rest of the survey questions.

Since the study was part of the user research project collaborating with MIT AgeLab 85^+ Lifestyle Leaders Panel, MIT AgeLab had already applied for and received exempt approval from the MIT Committee On the Use of Humans as Experimental Subjects (COUHES) to process the relevant study.

Appendix H—User Survey Design

Part 1. Introduction

Questionnaire about Indoor Footwear Design | Lifestyle Leaders Panel | July 2021



Dear Lifestyle Leaders,

Thank you for your willingness to participate in this survey. I am Sheng-Hung Lee, a second-year graduate student from the MIT Integrated Design & Management (IDM) program and Department of Mechanical Engineering, currently working with the MIT AgeLab as a research assistant co-advised by Dr. Joseph F. Coughlin and Dr. Chaiwoo Lee. My MIT master's thesis project is about designing a new type of indoor footwear for older adults and understanding related thoughts and perspectives that future users of such a product may have. Your invaluable input through this survey will greatly help advance our understanding of human-centered product design for the aging population.

It will take you approximately 15 to 20 minutes to complete this survey. You are welcome to skip any questions you do not want to answer. Please feel free to contact me if you have any concerns or questions. Below is my personal contact information and I would be more than happy to support you.

Sincerely,

Sheng-Hung Lee

MS Candidate, Integrated Design & Management (IDM) and Department of Mechanical Engineering
Massachusetts Institute of Technology
617-335-7115 | shdesign@mit.edu | https://www.shenghunglee.com/

Part 2. Consent Form

Question 2.1.

For each of the following questions, please select the best response based on your own thoughts and opinions. In some cases, you may select more than one answer. You do not need to answer any questions that you do not wish to. All responses will remain confidential. These questions will help us better understand people's needs for indoor footwear and related Internet of Things (IoT) devices.

Question 2.2.

Do you consent to participate in this online survey?

○ Yes

○ No

Part 3. Users' Wearing Behavior

Question 3.1.

First, we would like to know about your use of indoor footwear.

Question 3.2.

How many pairs of shoes (e.g., sneakers, loafers, sandals, boots) do you currently have in total **in your home**, including the shoes you own and use?

(Note: We mean **your own shoes**, not including the shoes of your spouse, children, or other family members.)

- ○ One pair only
- ○ 2 to 3 pairs
- ○ 4 to 5 pairs
- ○ More than 5 pairs

Question 3.3.

Which of the following spaces in your home do you consider to be an **“indoor” space**? Select all that apply.

☐ Living room

☐ Kitchen

☐ Bathroom

☐ Bedroom

☐ Garage

☐ Driveway

☐ Basement or cellar

☐ Porch or Deck

☐ Back and Front Yard(s)

☐ Other (please describe): ___________

Question 3.4.

How many “**indoor**” pairs of footwear do you have?

(Note: By “indoor footwear” we mean, footwear that is meant to be primarily worn indoors and not outdoors.)

○ I don't have any.

○ One pair only

○ 2 to 3 pairs

○ 4 to 5 pairs

○ More than 5 pairs

○ Others (please describe): ___________

Question 3.5.

Why do you wear indoor footwear at home? Select all that apply.

(Note: By "indoor footwear" we mean footwear that is meant primarily to be **worn indoors, but not outdoors.**)

- ☐ It makes my feet comfortable.
- ☐ It keeps my feet and body warm.
- ☐ It can massage my feet and make me relax.
- ☐ It prevents me from falling at home.
- ☐ It makes my home clean and hygienic.
- ☐ It looks decent and polite while I have guests at home.
- ☐ It is my family's tradition to separate indoor shoes and outdoor shoes.
- ☐ It is my indoor floor at home that requires me to put on indoor shoes.
- ☐ It is a ritual that makes me feel I am staying at home.
- ☐ Other reason(s) (please describe): ___________

Question 3.6.

In a typical day, how many hours do you tend to wear your **indoor footwear** when you are **at home**?

- ○ Less than 1 hour
- ○ 1 hour or more but less than 4 hours
- ○ 4 hours or more but less than 7 hours
- ○ 7 hours or more but less than 10 hours
- ○ 10 hours or more

Question 3.7.
What time of **day** do you wear **indoor footwear** more often? Select all that apply.

- ☐ Morning
- ☐ Midday
- ☐ Afternoon
- ☐ Evening
- ☐ No, I wear them just as often during all these times.
- ☐ Other (please describe): ____________

Question 3.8.
What **season** do you wear your **indoor footwear** more often? Select all that apply.

- ☐ Spring
- ☐ Summer
- ☐ Fall
- ☐ Winter
- ☐ No, I wear them just as often during all these times.
- ☐ Other (please describe): ____________

Question 3.9.
What kind of indoor footwear do you **wear the most often**?

- ○ Slippers
- ○ Flip-flops
- ○ Boots
- ○ Sandals
- ○ Sneakers
- ○ Non-skid socks
- ○ Something else (please describe): ____________

Question 3.10.
Do you **store** your indoor footwear anywhere in particular in home when you take them off?

○ Yes

○ No, I will take them off and leave them anywhere.

Question 3.11.
Where do you typically **store your footwear** at home?

____

Question 3.12.
Think about the pair of indoor footwear **you wear the most often in a day**. Where do you most often put or store that footwear if you want to **take them off for a while**? Select all that apply.

☐ Near my bed where I sleep.

☐ Somewhere in the living room.

☐ Somewhere in the bathroom.

☐ In a shoe rack.

☐ No specific area in my home.

☐ Depends on the day and activities.

☐ Other (please describe): ___________

Question 3.13.
Please select which of the following most closely describes how you **put on** your indoor footwear. Select all that apply.

☐ I put on my indoor footwear without using my hands.

☐ I use one hand to adjust the room/space of my toe box or heel to help me put on the indoor footwear.

☐ I use both hands to help me put on my indoor footwear.

☐ Another person helps me put on my indoor footwear.

☐ I use an assistive device to help me put on my indoor footwear.

☐ Other (please describe): ___________

Question 3.14.

Please select which of the following most closely describes how you **take off** your indoor footwear. Select all that apply.

- ☐ I take off my indoor footwear without using my hands.
- ☐ I use one hand to help me take off my indoor footwear.
- ☐ I use both hands to help me take off my indoor footwear.
- ☐ Another person helps me take off my indoor footwear.
- ☐ I use an assistive device to help me take off my indoor footwear.
- ☐ Other (please describe): ___________

Question 3.15.

How **comfortable** are you with how well your primary pair of indoor footwear fits your feet?

- ○ Very comfortable
- ○ Somewhat comfortable
- ○ Neither uncomfortable nor comfortable
- ○ Somewhat uncomfortable
- ○ Very uncomfortable

Question 3.16.

What are some of the most **frustrating things** you experience in regards to your indoor footwear? Select all that apply.

- ☐ Sometimes it is not easy for me to find my indoor footwear inside of my home.
- ☐ I feel my indoor footwear does not really fit my feet.
- ☐ I don’t have a habit of putting on indoor footwear while at home.
- ☐ Something else (please describe): ___________

Question 3.17.

Please select the following images that best describe your **current feelings** about when you put on your **most frequently worn** pair of indoor footwear? Select all that apply.

☐ Image 1

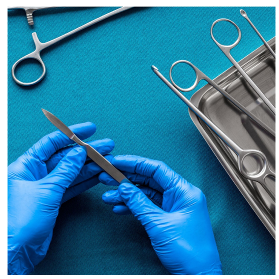
☐ Image 2

☐ Image 3

☐ Image 4

☐ Image 5

☐ Image 6



☐ Image 7

☐ Image 8

☐ Image 9

☐ Image 10

Question 3.18.

Please select the images that reflect the experience of **your ideal indoor footwear**. Select all that apply.

Question 3.19.
Please write in up to **two keywords** that come to your mind when you look at the **image 1**.

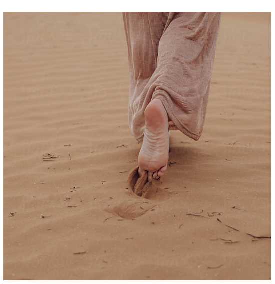
Keyword #1: ___________
Keyword #2: ___________

Question 3.20.
Please write in up to **two keywords** that come to your mind when you look at the **image 2**.

Keyword #1: ___________
Keyword #2: ___________

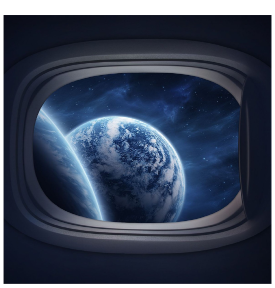
Question 3.21.
Please write in up to **two keywords** that come to your mind when you look at the **image 3**.

Keyword #1: ___________
Keyword #2: ___________



Question 3.22.
Please write in up to **two keywords** that come to your mind when you look at the **image 4**.

Keyword #1: ___________
Keyword #2: ___________



Question 3.23.
Please write in up to **two keywords** that come to your mind when you look at the **image 5**.

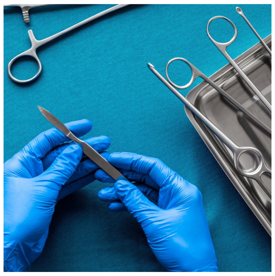
Keyword #1: ___________
Keyword #2: ___________

Question 3.24.

Please write in up to **two keywords** that come to your mind when you look at the **image 6**.

Keyword #1: ___________

Keyword #2: ___________



Question 3.25.

Please write in up to **two keywords** that come to your mind when you look at the **image 7**.

Keyword #1: ___________

Keyword #2: ___________

Question 3.26.

Please write in up to **two keywords** that come to your mind when you look at the **image 8**.

Keyword #1: ___________

Keyword #2: ___________

Question 3.27.

Please write in up to **two keywords** that come to your mind when you look at the **image 9**.

Keyword #1: ___________

Keyword #2: ___________

Question 3.28.

Please write in up to **two keywords** that come to your mind when you look at the **image 10**.

Keyword #1: ___________

Keyword #2: ___________

Question 3.29.

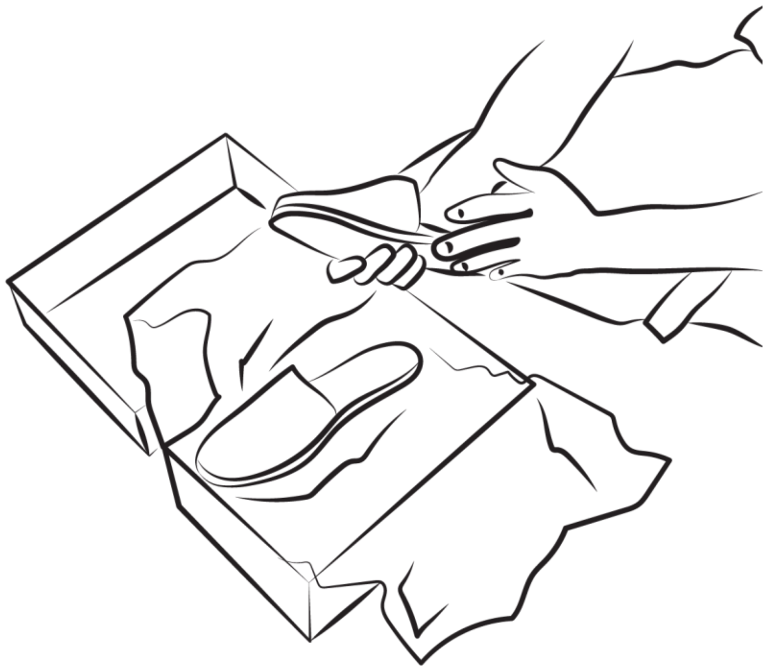
Imagine in the future if you were to have **a pair of high-end or better quality indoor footwear**, ideally, which **professional services and experiences** would you be the most interested in having with regard to your indoor footwear? Select all that apply.

- ☐ A professional measures your feet correctly before you purchase the indoor footwear.
- ☐ A professional shares with you the relevant information and tips about your feet, mobility and about choosing an appropriate a pair of indoor footwear.
- ☐ A professional provides a one-year after-sale service to keep your indoor footwear in a good condition.
- ☐ A professional repairs your indoor footwear when needed at your home.
- ☐ The option to register for a(n) virtual/in-person tutorial giving the latest trends and academic research on indoor footwear.
- ☐ The option to subscribe to a newsletter from your indoor footwear company containing advice and tips about feet, mobility, and choosing an appropriate pair of indoor footwear.
- ☐ A company provides a toolkit or set of accessories to maintain your indoor footwear.
- ☐ None of the above
- ☐ Something else (please describe): ___________

Part 4. Users' Purchasing Behavior

Question 4.1.

Now, we would like to know about your purchasing of indoor footwear.



Question 4.2.

What do you consider to be a **suitable price** for a pair of indoor footwear that you would purchase for yourself? Select all that apply.

- ☐ Below 10 dollars
- ☐ 11-25 dollars
- ☐ 26-50 dollars
- ☐ 51-100 dollars
- ☐ 101-125 dollars
- ☐ 126-150 dollars
- ☐ 151-175 dollars
- ☐ 176-200 dollars
- ☐ Over 200 dollars
- ☐ Another amount (please list): ___________

Question 4.3.

Who usually purchases your indoor footwear?

- ○ Myself
- ○ My family purchases indoor footwear for me.
- ○ Someone else (please describe): ___________

Question 4.4.

How important are each of the following **factors** to you when you are **purchasing** indoor footwear?

	not important at all	a little important	somewhat important	very important	extremely important
The texture or material of the shoes	○	○	○	○	○
The brand of the shoes	○	○	○	○	○
The comfort of the shoes	○	○	○	○	○
The ease of getting the shoes on/off	○	○	○	○	○
The size or overall fitness of shoes	○	○	○	○	○
The weight of the shoes	○	○	○	○	○
The price of the shoes	○	○	○	○	○
The after-sale service of the shoes	○	○	○	○	○
Recommendation(s) from family and friends	○	○	○	○	○
My doctor's recommendation(s)	○	○	○	○	○

Question 4.5.

How often do you typically **replace** your indoor footwear?

- ○ Once per month or more often
- ○ Every 2~3 months
- ○ Every 4~6 months
- ○ 1~2 times per year
- ○ Less often than yearly

Question 4.6.

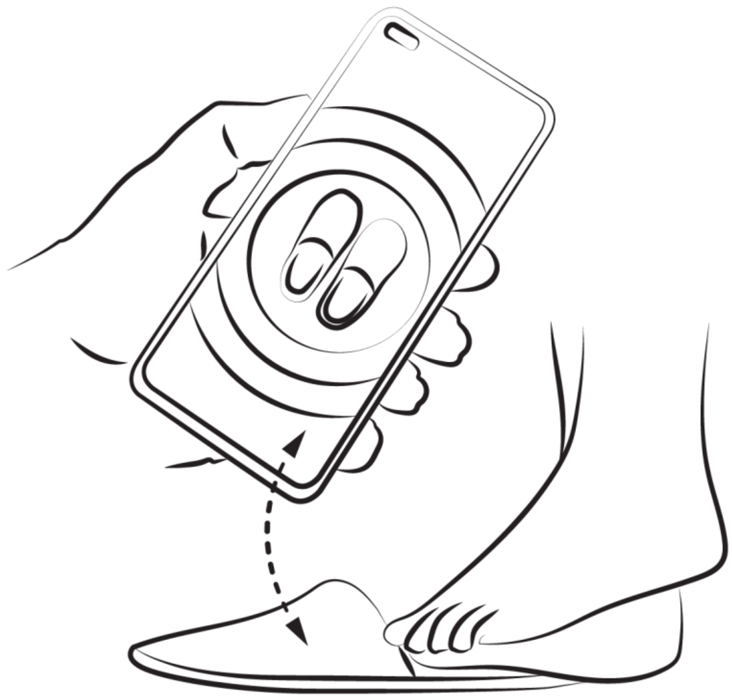
Do you prefer certain **brand(s)** of indoor footwear?

- ○ Yes. They are: ____________
- ○ No, I do not prefer any particular brands of indoor footwear.
- ○ Don't know/Unsure.

Part 5. About Smart Footwear

Question 5.1.

Now, we would like to know about your understanding of **smart footwear**.



Question 5.2.

Given the various levels of automation that **smart wearable devices** can have, what **level of automation** would you be comfortable with your smart wearable devices?

"Program" in the options below refers to a standard computer language that can make the product function and operate as the product team/company design and predict.

- ○ The devices need to be set up before I can use it. It follows a fixed program.
- ○ The device has three options of the automation level from simple, medium to advanced. But it still follows a fixed program.
- ○ The device needs to be trained to know my personal preference.
- ○ The device will self-improve based on my behavior, but it can't predict my next step.
- ○ The devices treat me like a close friend that understands me and can predict my next step.

Question 5.3.

According to Oracle's definition, the **Internet of Things (IoT)** describes the network of physical objects—"things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.

We want to know how comfortable you are with the idea of **IoT wearable devices** sharing the **data** it collects about you on the cloud?

○ Not at all comfortable. I don't want a device to store any of my personal data.

○ A little comfortable

○ Somewhat comfortable

○ Very comfortable

○ Extremely comfortable. I would be willing to share my data on the cloud with others.

Question 5.4.

Please complete the following sentence.

Designing with data means to: ____

Question 5.5.

Which of the following **functions** would you want an **IoT wearable device** (not just a pair of smart indoor footwear) to help you with? Select all that apply.

☐ Improve my efficiency

☐ Increase my creativity

☐ Optimize my time

☐ Make my life convenient

☐ Connect me with other people

☐ Other (please describe): ___________

Question 5.6.

What words come to your mind when you hear the term "**smart footwear**"?

Keyword #1: ___________
Keyword #2: ___________
Keyword #3: ___________

Question 5.7.

What sorts of things do you think **smart footwear** could do for you? Select all that apply.

- ☐ Smart footwear can understand my needs.
- ☐ Smart footwear can make my life more convenient.
- ☐ Smart footwear can help me engage with the community.
- ☐ Smart footwear can assist me with my daily routine.
- ☐ Smart footwear can boost my confidence in life.
- ☐ Smart footwear can maintain my mental and physical well-being.
- ☐ Something else (please describe): ___________

Question 5.8.

If you had a pair of smart indoor footwear, what **functions** would you want the footwear to have? Select all that apply.

- ☐ Help me to exercise
- ☐ Help me relieve pain
- ☐ Help detect and collect information about my health condition(s) (e.g., blood pressure, pulse, gait)
- ☐ Control my home appliance(s)
- ☐ Communicate with other people
- ☐ Track my indoor trajectory
- ☐ Serve as a personal assistant
- ☐ Help me to relax
- ☐ Keep my feet warm/consistent temperature
- ☐ Prevent me from falling
- ☐ None of the above
- ☐ Something else (please describe): ___________

Question 5.9.

Think about your **own footwear needs and desires**, and please rate how interested you are in each of the following indoor footwear concepts on the following page.

Concept 1

The indoor footwear is like thick socks. It is very flexible and comfortable and feels just like your feet are wrapped in very soft fabric that makes you feel intimate.

Question 5.10.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.11.

Any suggestions, questions, or thoughts for **concept 1**?

____

____

____

____

Concept 2

The indoor footwear is designed with strong, friction-proof shoe soles. People are less likely to fall down if they wear them properly.

Question 5.12.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.13.

Any suggestions, questions, or thoughts for **concept 2**?

____

____

____

____

Concept 3

The indoor footwear is designed with multiple modular functions. People can plug and play in different scenarios at home to make their life more convenient and do things like tracking their health condition(s).

Question 5.14.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.15.

Any suggestions, questions, or thoughts for **concept 3**?

____

____

____

____

Concept 4
The indoor footwear is made from one piece of smart fabric with embedded sensors. People can easily wash it and select the colors, patterns, and graphics of the fabric paired with tailor-made shoelaces.

Question 5.16.
Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.17.
Any suggestions, questions, or thoughts for **concept 4**?

____

____

____

____

Concept 5
The indoor footwear looks like a typical pair of sandals but is embedded with high-tech sensors. People won't feel the difference between the typical/traditional scandals. All functions are controlled through its phone app.

Question 5.18.
Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.19.
Any suggestions, questions, or thoughts for **concept 5**?

____

____

____

____

Concept 6

Even though this ice-cream-cone-shaped indoor footwear is designed without full heel support, it is designed to make people feel like they are very comfortable walking without shoes. It is composed of one piece of smart fabric embedded with high-tech sensors.

Question 5.20.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.21.

Any suggestions, questions, or thoughts for **concept 6**?

____

____

____

____

Concept 7

The indoor footwear is designed with an air-supported shoe sole and other smart sensors to adjust people's feet ergonomically. Its structure makes people feel like they are delightfully walking on air.

Question 5.22.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.23.

Any suggestions, questions, or thoughts for **concept 7**?

____

____

____

____

Concept 8

The indoor footwear has two parts to be tied to people's feet with minimal surfaces: instep support strip and toe thumb. It provides the maximum space to let people's feet breathe and relax.

Question 5.24.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.25.

Any suggestions, questions, or thoughts for **concept 8**?

____

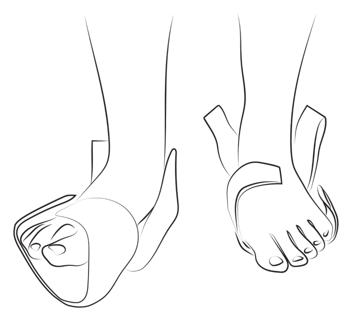
____

____

____

Concept 9

The indoor footwear will automatically attach and adapt to people's feet once it detects people's weight and the shape of their feet.



Question 5.26.

Level of interest:

- ○ Not at all interested
- ○ Slightly interested
- ○ Moderately interested
- ○ Very interested
- ○ Extremely interested

Question 5.27.

Any suggestions, questions, or thoughts for **concept 9**?

____

____

____

____

Concept 10
The indoor footwear will generally adapt to its friction level through smart material texture according to the size of people's feet and their walking pattern.

Question 5.28.
Level of interest:

○ Not at all interested

○ Slightly interested

○ Moderately interested

○ Very interested

○ Extremely interested

Question 5.29.
Any suggestions, questions, or thoughts for **concept 10**?

____

____

____

____

Question 5.30.
If you were given one of these new pairs of footwear for free, which would you be the **most interested in**?

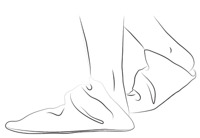

○ Concept 1


○ Concept 2


○ Concept 3

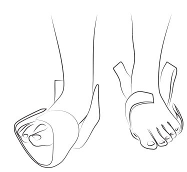

○ Concept 4


○ Concept 5


○ Concept 6


○ Concept 7


○ Concept 8


○ Concept 9

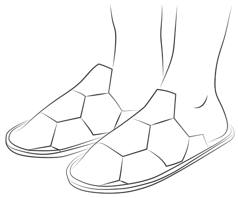

○ Concept 10

Question 5.31.
Why is this pair the most interesting to you? (please describe)

____

Question 5.32.
Why is this pair the most interesting to you? (please describe)

____



Question 5.33.
Why is this pair the most interesting to you? (please describe)

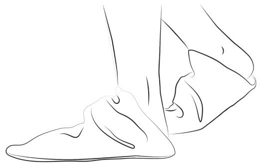
____

Question 5.34.
Why is this pair the most interesting to you? (please describe)

____

Question 5.35.
Why is this pair the most interesting to you? (please describe)

____



Question 5.36.
Why is this pair the most interesting to you? (please describe)

____

Question 5.37.
Why is this pair the most interesting to you? (please describe)

____

Question 5.38.
Why is this pair the most interesting to you? (please describe)

____

Question 5.39.
Why is this pair the most interesting to you? (please describe)

____

Question 5.40.
Why is this pair the most interesting to you? (please describe)

____

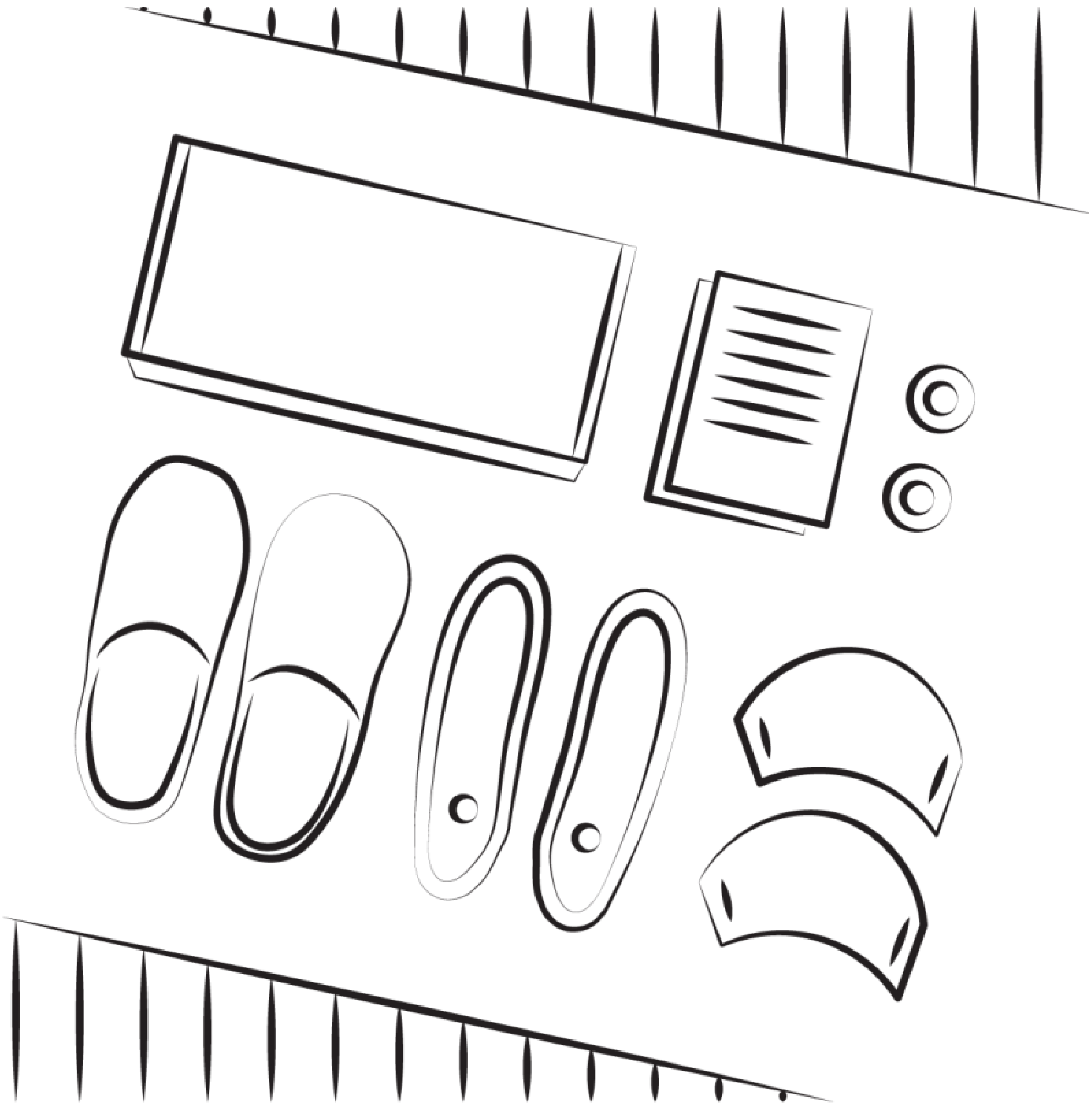
Part 6. Others

Question 6.1.

Do you have **any other thoughts, ideas, and suggestions** related to indoor footwear that you would like to share with us?

Question 6.2.

(Transition image to Part 7)



Part 7. Demography

Question 7.1.

Before finishing the survey, we have a few final questions in which we will ask for some demographic information.

Question 7.2.

What is your first name?

____

Question 7.3.

What is your last name?

____

Question 7.4.

With which gender do you most identify?

○ Male

○ Female

○ Prefer to self-describe: ____________

○ Prefer not to answer

Question 7.5.
In what **year** were you born?

____

Question 7.6.
What was your **occupation** before you retired? If you are currently working for pay, what sort of work do you do these days?

____

Question 7.7.
What is your **favorite hobby** these days?

☐ Sports

☐ Music

☐ Arts

☐ Reading

☐ Others (please describe): ___________

Question 7.8.
Who do you currently live with?

○ I live with my family.

○ I live with people with whom I'm not related (non-family).

○ I live by myself.

Question 7.9.
How many people (either family or non-family members) live in your household, **including yourself**?

- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6 or more people

Question 7.10.
How would you **best** describe the **home** where you currently live?

- ○ A single-family home
- ○ A multi-family home
- ○ A building such as an apartment, condo, or townhome
- ○ A senior housing community
- ○ Others (please describe): ___________

Question 7.11.
These days, in a typical day, how much time do you spend **outdoors**?

- ○ Less than 1 hour
- ○ 1 hour or more but less than 3 hours
- ○ 3 hours or more but less than 5 hours
- ○ 5 hours or more but less than 8 hours
- ○ More than 8 hours

Question 7.12.
These days, in a typical day, how much time do you spend **inside** of your home?

- ○ Less than 1 hour
- ○ 1 hour or more but less than 3 hours
- ○ 3 hours or more but less than 5 hours
- ○ 5 hours or more but less than 8 hours
- ○ More than 8 hours

End of Survey

We thank you for your time spent taking this survey.
Your response has been recorded.

Appendix I—User Survey Mood Board

In the user survey, we used ten different images as mood boards to probe participants' initial thoughts and asked them to write two keywords per image that come to their mind when they look at the following ten images (Table I.1.). In Appendix I, we not only documented the keywords of each image but also explained the intention of selecting the following ten images that are relevant to our indoor footwear design for older adults to test the hypothesis of our study.

Table I.1. Mood board images overview (same as Table 6.3. and sources from the Internet)

Image 1

Image 2

Image 3

Image 4

Image 5

Image 6

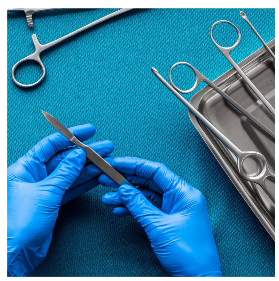


Image 7

Image 8

Image 9

Image 10

Mood Board Image 1

The intention of using image 1
When we conducted the user interview, one interviewee said, “Wearing a good pair of slippers is like walking on the cloud.” Therefore, it inspired us to find whether this mood board image can resonate with other interviewees.

Table I.2. Keywords of image 1 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• relax	5	• slippery	1	• relax	2
• comfortable	2	• wide-open	1	• quiet	1
• open	2	• wide	1	• walking	1
• quiet	2	• soft	1	• summer	1
• travel	1	• peaceful	1	• soft	1
• coolness	1	• comfortable	1	• freedom	1
• smooth	1	• ice	1	• clean	1
• mirrored	1	• peaceful	1	• carefree	1
• freedom	1	• clear	1		
• cool	1	• on a cloud	1		
• comfy	1	• reflection	1		
• comfort	1	• light	1		
• flat	1				
• in good mood	1				
• spacious	1				
• calm	1				
• soothing	1				
• excited	1				
• calm	1				
• light	1				
• leisure	1				

Mood Board Image 2

The intention of using image 2
Image 2 is to present the comfort people can feel when they lie on green grass to enjoy fresh air and sunshine, and get close to nature.

Table I.3. Keywords of image 2 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• comfortable	8	• relax	10	• relax	4
• relax	7	• comfortable	10	• comfort	3
• free	3	• easy	2	• relaxing	2
• comfort	3	• cozy	2	• restful	2
• relaxing	2	• cool	2	• comfortable	2
• freedom	2	• relief	1	• steady	1
• dry	1	• release	1	• relaxed	1
• accompany	1	• relaxing	1	• peaceful	1
• de-stress	1	• relaxed	1	• home	1
• people	1	• quiet	1	• eden!	1
• peaceful	1	• mindless	1	• dreamy	1
• reliable	1	• no burden	1	• delightful	1
• cool	1	• care-free	1	• sturdy	1
• leisurely	1	• happy	1	• feeling	1
• flashbacks	1	• loose	1	• thoughtful	1
• fresh	1	• clean	1	• happy	1
• clean	1	• No burden	1	• bliss!	1
• ventilate	1	• peace	1	• timeless	1
• ease	1	• carefree	1	• rest	1
• soft	1	• fresh	1	• relaxation	1
• breathable	1	• warm	1		
• unencumbered	1	• soft	1		
• nature	1	• healthy	1		

Mood Board Image 3

The intention of using image 3

Image 3 shows the level of humidity, heat, and discomfort for the cook and waiters working in a traditional Chinese restaurant. We want to see if our participants can relate their footwear wearing experience, such as pain, discomfort, and inability to breathe to this image.

Table I.4. Keywords of image 3 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• No keywords	0	• No keywords	0	• No keywords	0

Mood Board Image 4

The intention of using image 4
Image 4 presents a sense of peace, comfort, and calm for people walking in open spaces such as deserts. Participants can clearly see the bottom of people's feet, which indicates that the footwear wearing experience can make people feel clean, hygienic, dry (of the feet), or in a healthy condition.

Table I.5. Keywords of image 4 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• soft	7	• relax	4	• warm	2
• comfortable	2	• firm	2	• soft	2
• dry	2	• conformal	2	• comfortable	2
• soft and tender	1	• soft and tender	1	• relaxing	1
• flabby	1	• soft	1	• passive	1
• stick	1	• relax	1	• good	1
• comfort	1	• dry	1	• free	1
• bare	1	• free	1	• casual	1
• powerless	1	• de-stress	1	• massage	1
• sunken	1	• comfortable	1	• free	1
• afflictive	1	• easy	1	• support	1
• wide	1	• penetrate	1	• open minded	1
• delicate	1	• non-slip	1	• sensation	1
• flexible	1			• soft	1
• warm	1			• unencumbered	1
• nature	1				

Mood Board Image 5

The intention of using image 5
We want to encapsulate the vibe of outer space: quiet, lonely, and as if people have a conversation with their inner self inspired by image 5, which also reflects how difficult it is for them to wear shoes, or how urgent and often they need to ask for help in terms of product's usability or after-sale service, especially for older adults.

Table I.6. Keywords of image 5 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• freezing cold	1	• airplane	1	• roam	1
• space	1	• quiet	1	• slow	1
• soundless	1	• business trip	1		
• soft	1	• comfortable	1		
• quite	1				
• heaven	1				
• freedom	1				
• floating	1				
• quiet	1				
• tech	1				
• weightless	1				
• clean	1				
• silent	1				
• peace	1				
• mystery	1				
• fashion	1				

Mood Board Image 6

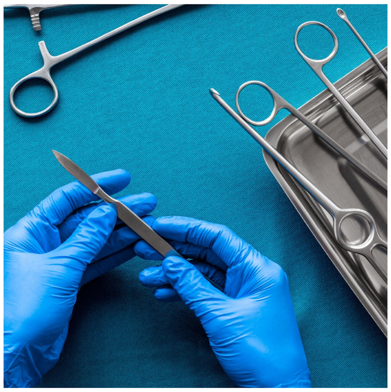
The intention of using image 6

Image 6 sends a message of a surge of excitement, adventure, joy, and achievement while people wear shoes. Since surfing is an extreme sport, we want to translate the surfing experience to people's footwear-wearing experience.

Table I.7. Keywords of image 6 (n means number of keywords shown)

Group A (aged 18~30)		Group B (aged 31~60)		Group C (aged 61~100)	
Keywords	n	Keywords	n	Keywords	n
• content	1	• comfortable	1	• fast	1
• excitement	1	• surfing	1	• adventure	1
• coolness	1	• fly upward	1	• cool	1
• soft	1	• sports	1	• freedom	1
• lithe	1				
• freedom	1				
• free	1				
• excitement	1				
• freezing cold	1				
• happy	1				
• unlimited	1				
• happy	1				
• stimulate	1				
• light	1				

Mood Board Image 7



The intention of using image 7
Image 7 reveals the preciseness and conciseness of the experience, which can show the importance of the fitness of the shoe for customers, specifically for older adults. Another aspect that we interpret from image 7 is to think about the coldness, unawareness, and distance of people's footwear-wearing or purchasing experience.

Table I.8. Keywords of image 7 (n means number of keywords shown)

Group A (aged 18~30)		Group B (aged 31~60)		Group C (aged 61~100)	
Keywords	n	Keywords	n	Keywords	n
• No keywords	0	• No keywords	0	• No keywords	0

Mood Board Image 8

The intention of using image 8
Image 8 transmits the message of people shaking, being scared, fearing falling down, and moving forward while they are wearing shoes or walking. The opposite of the meaning of image 7 is to interpret people's courage to keep moving towards their goal, which means persistence or building trust in certain footwear brands.

Table I.9. Keywords of Image 8 (n means number of keywords shown)

Group A (aged 18~30)		Group B (aged 31~60)		Group C (aged 61~100)	
Keywords	n	Keywords	n	Keywords	n
• No keywords	0	• No keywords	0	• No keywords	0

Mood Board Image 9

The intention of using image 9
Image 9 is to show people gathering, collaboration, family warmth, celebration, and contentment in life. We want to see if participants can feel an atmosphere similar to that inspired by the hot pot experience.

Table I.10. Keywords of image 9 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
● lively	1	● gathering	1	● No keywords	0
● reunion	1	● having meal	1		
● family	1				
● carefree	1				
● delicious	1				
● reunion	1				

Mood Board Image 10

The intention of using image 10

Image 10 represents speed, efficiency, momentum, and high performance for people walking in shoes. We want to see if survey participants feel a similar experience or can resonate with their other life experience.

Table I.11. Keywords of image 10 (n means number of keywords shown)

Group A (aged 18~30)		**Group B (aged 31~60)**		**Group C (aged 61~100)**	
Keywords	n	Keywords	n	Keywords	n
• fun • efficient	1 1	• slippery • fall down	1 1	• No keywords	1

Appendix J—User Survey Design Concept

In the user survey, we used ten early-stage design concepts (Table J.1.) to probe participants' feedback in terms of their interest, divided by five levels from not at all interested, slightly interested, moderately interested, very interested to extremely interested. We can observe the difference between groups (three different age ranges) and how it connects to their lifestyle, behavior, health conditions, hobbies, demographics, and family.

In each design concept document sheet, we have concept illustration, concept description, participants' interest level diagram, and participants' anonymous feedback. The information above has greatly helped us to not only capture participants' inspiration but also understand what product features people are interested in and how we can address their pain points accordingly.

Table J.1. Design concept overview (same as Table 6.6. and illustrated by Sheng-Hung Lee)

				
Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
				
Concept 6	Concept 7	Concept 8	Concept 9	Concept 10

Concept 1

Concept description

The indoor footwear is like thick socks. It is very flexible and comfortable and feels just like your feet are wrapped in very soft fabric that makes you feel intimate.

Figure J.1. Participants' interests level towards concept 1

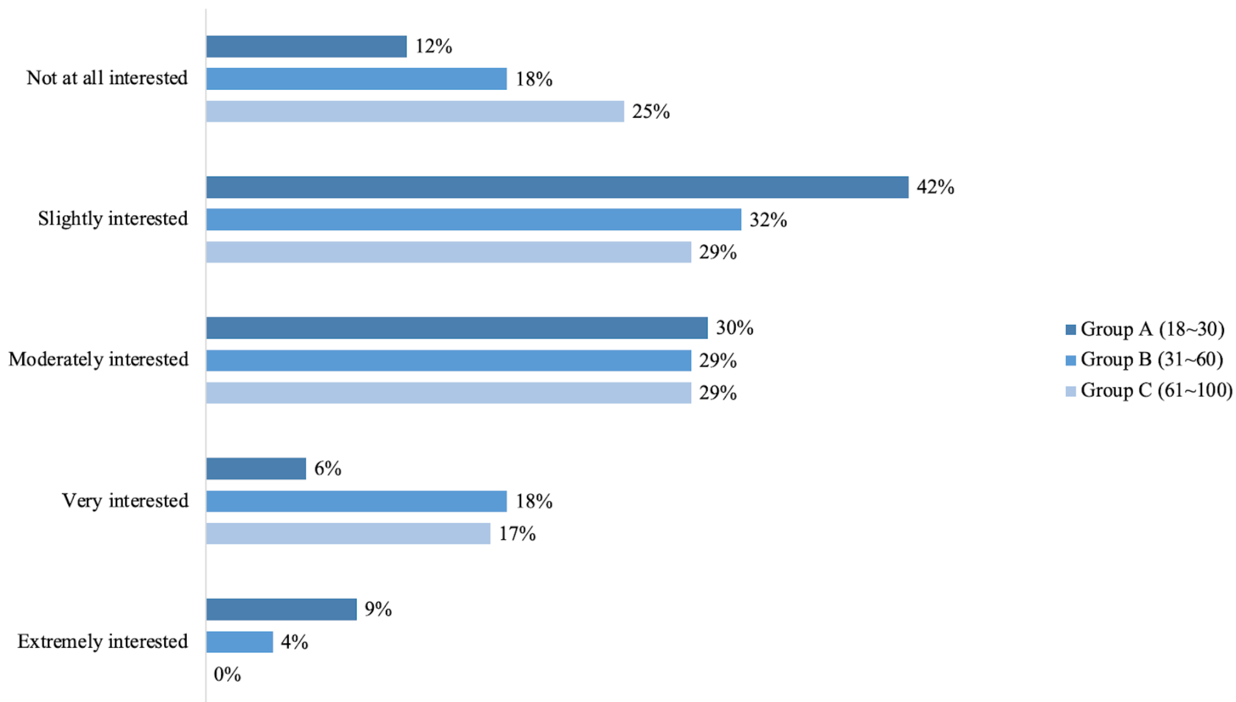
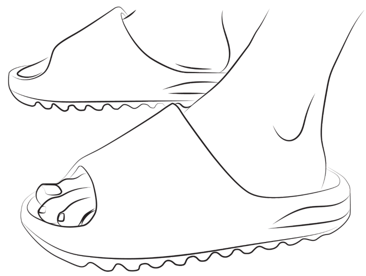


Table J.2. Anonymous participants' feedback for concept 1

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• Concern if the material is strong enough to protect the feet, since it is very soft. We can pay attention to thickness and lightness. • It's like wearing socks and it's very damp. It needs to differentiate with socks. I don't want to put them on or take them off with my hands. • I hope it can create really relaxing experiences, but I have doubts on	• We need to consider the season to wear this footwear., and if it's too hot to wrap. The footwear can use very light materials with breathable and quick-dryingfeatures like . It cannot be too tight when people put them on. The concept may need to include some sole support and can match for sweat	• The concept can be too slippery on wood floors for an aging population. • A non-slip feature can protect from objects, cuts, and bruises. • I think my feet need more support and I still need to use my hands to put them on. It is easy to put in shape. • It is good in the wintertime when I

the footwear maintenance and if it is an easy-wearing experience.	absorption, deodorization and washing. ● If I need to wear a pair, I want it to be easy to take off. Socks are not easy to take off for me.	take my boots off indoors. ● Depends on the season to decide if I should wear it. I need to be careful that my feet do not overheat.

Concept 2



Concept description

The indoor footwear is designed with strong, friction-proof shoe soles. People are less likely to fall down if they wear them properly.

Figure J.2. Participants' interests level towards concept 2

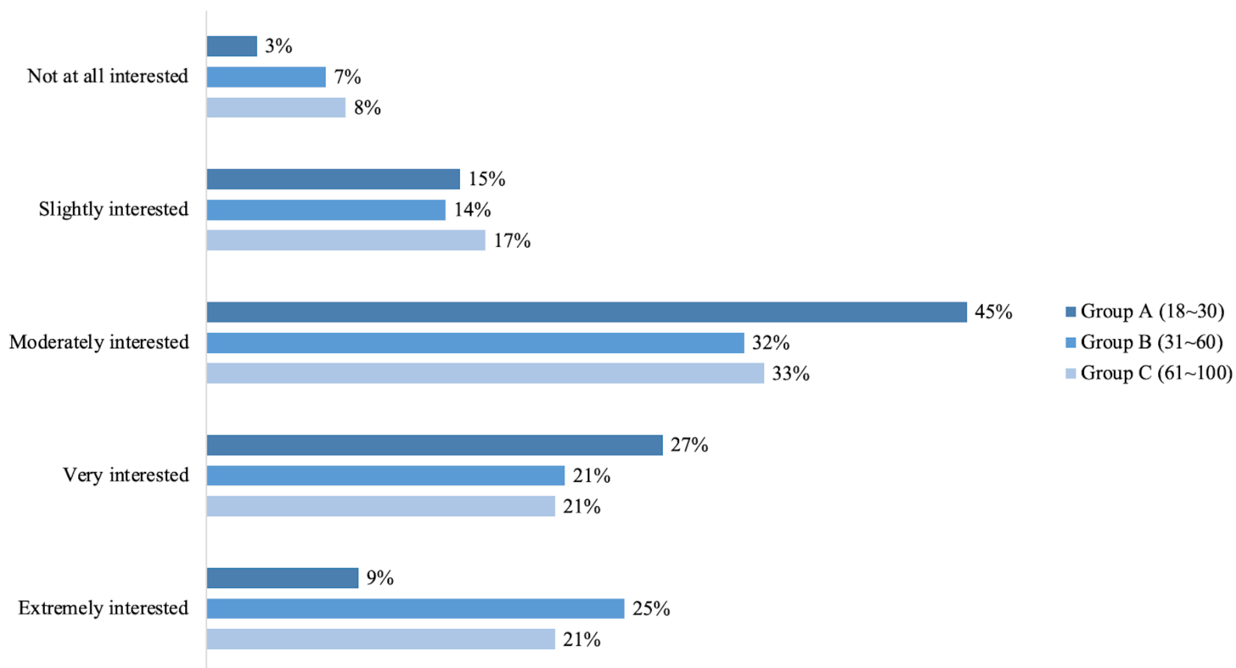
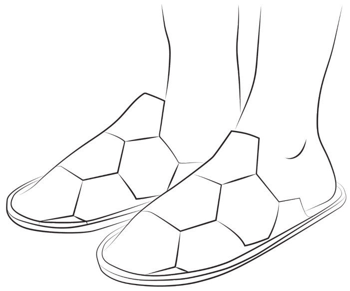


Table J.3. Anonymous participants' feedback for concept 2

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• The concept should not be smelly and sweaty. • It makes people feel it is a safe design. • Maybe it looks too thick; and the feeling that it created is a little tiring. • It feels good and can be taken off and worn at any time. • I think helping people not fall down also has something to do with the style of shoes. I hope it has a more attractive appearance.	• The bottom of the shoe sole needs to be a bit soft because the material is too hard, uncomfortable, and easy to make people fall. I prefer that the toes be covered. • The weight and height of the shoes will be the focus of consideration. Non-slip, light, and comfortable. The concept could cause instep eczema and I would use the term "slip-proof" in the concept description. This concept can be suitable for elders in the family.	• I like this washable concept. • Probably this is a needed concept despite what people think. Open-toed design is not good for bunions and also needs back on footwear. • Make sure they don't hurt anything • It looks very comfortable. The design language cannot be too heavy. • I never want open-toed indoor footwear. Items I drop fall on my toes.

	● I don't like lug soles.

Concept 3



Concept description
The indoor footwear is designed with multiple modular functions. People can plug and play in different scenarios at home to make their life more convenient and do things like track their health condition(s).

Figure J.3. Participants' interests level towards concept 3

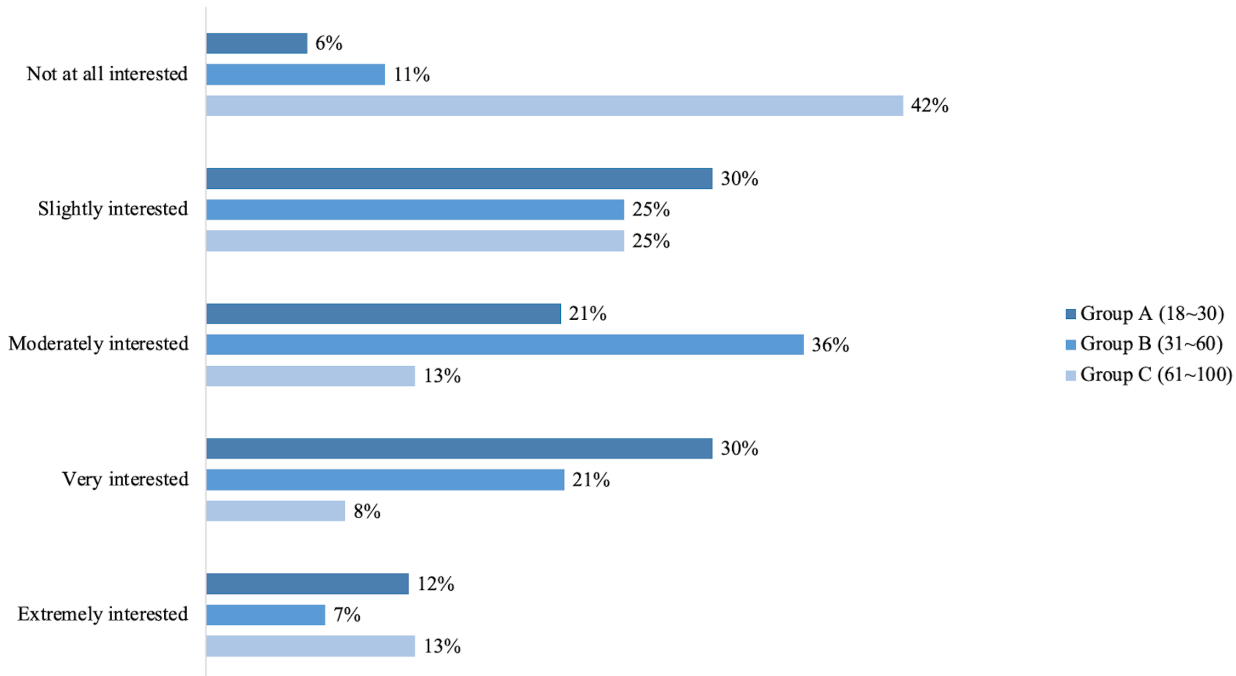


Table J.4. Anonymous participants' feedback for concept 3

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• The concept sounds very people-centered and convenient. I am looking forward to having multiple functions with modularities. • It is interesting but not useful. • In my opinion, a pair of shoes should not be equipped with too many or too complicated functions. • This is a very cool idea, and I may buy one! And I think the concept is	• Mode shifting needs to be designed easily and conveniently. • Can the concept be washable? • This concept is too complicated. • Step weight information to improve walking stability. • Record reading is kind of fun • The design looks healthy and simple! • I don't think my parents would understand how you worded this	• Sometimes I need to change my indoor shoes to a courtyard for a short time. It is very necessary. I am wondering if the concept can track people's pulse, BP, temp, EKG? • Must have a back to stay on my very flat feet and I have to wear orthopedics. I like open-toed shoes, but I think my feet would get too hot. It's an ideal solution

designed for convenience.	● It is a very clean sole design. ● Available all year round, APP control.	for me as an older adult. ● The concept is too complicated for older adults. As shown, it appears to need more support from others.

Concept 4

Concept description

The indoor footwear is made from one piece of smart fabric with embedded sensors. People can easily wash it and select the colors, patterns, and graphics of the fabric paired with tailor-made shoelaces.

Figure J.4. Participants' interests level towards concept 4

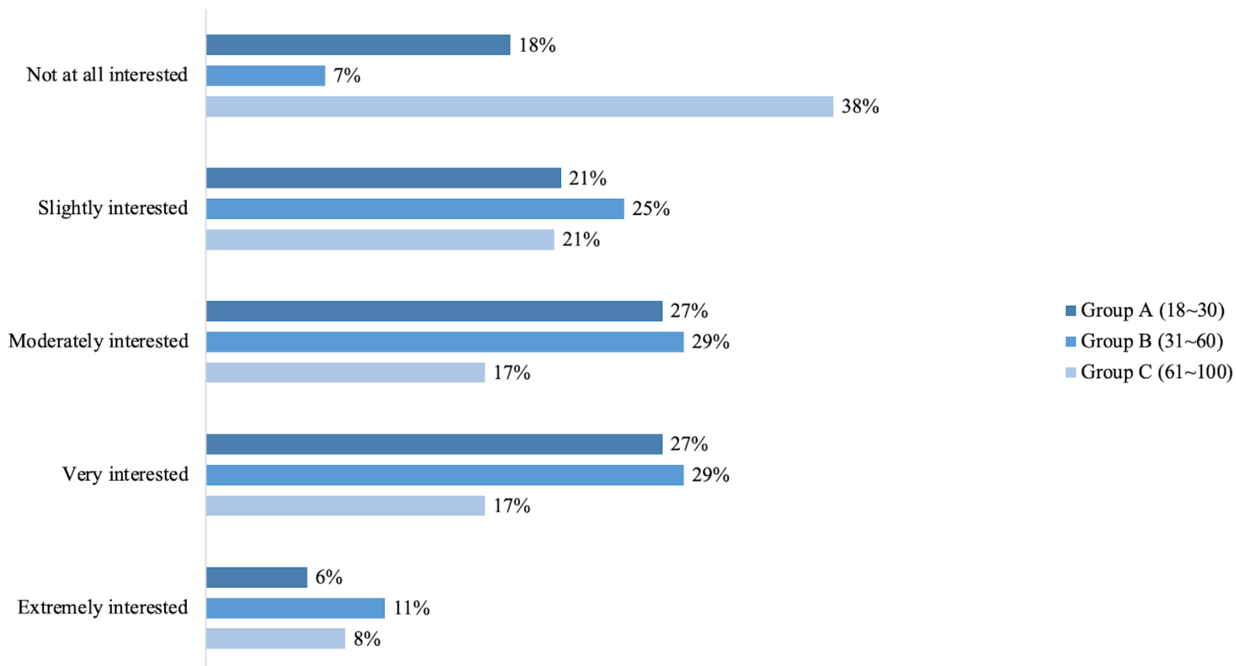


Table J.5. Anonymous participants' feedback for concept 4

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• With such cool shoes, people should wear them outdoors. • I like the customized design. • Potentially, we can think about how to design with good patterns.	• The beauty of simplicity. • When I clean my shoes, it might decrease the time of washing. • This is not a practical solution in hot seasons. • Modularity suitable for any shoe in various scenarios. • It looks like a fantasy concept.	• It is an unnecessary technology. • Good, there is a back but I need my orthopedic maybe unless this design concept can build it into the smart shoe. • Good for different emotions older adults have. • Doesn't look like these offer any support. • It is a "cute" design, But how about the support of the feet? • I like the creativity of the concept.

Concept 5

Concept description
The indoor footwear looks like a typical pair of sandals but is embedded with high-tech sensors. People won't feel the difference between the typical/traditional sandals. All functions are controlled through its phone app.

Figure J.5. Participants' interests level towards concept 5

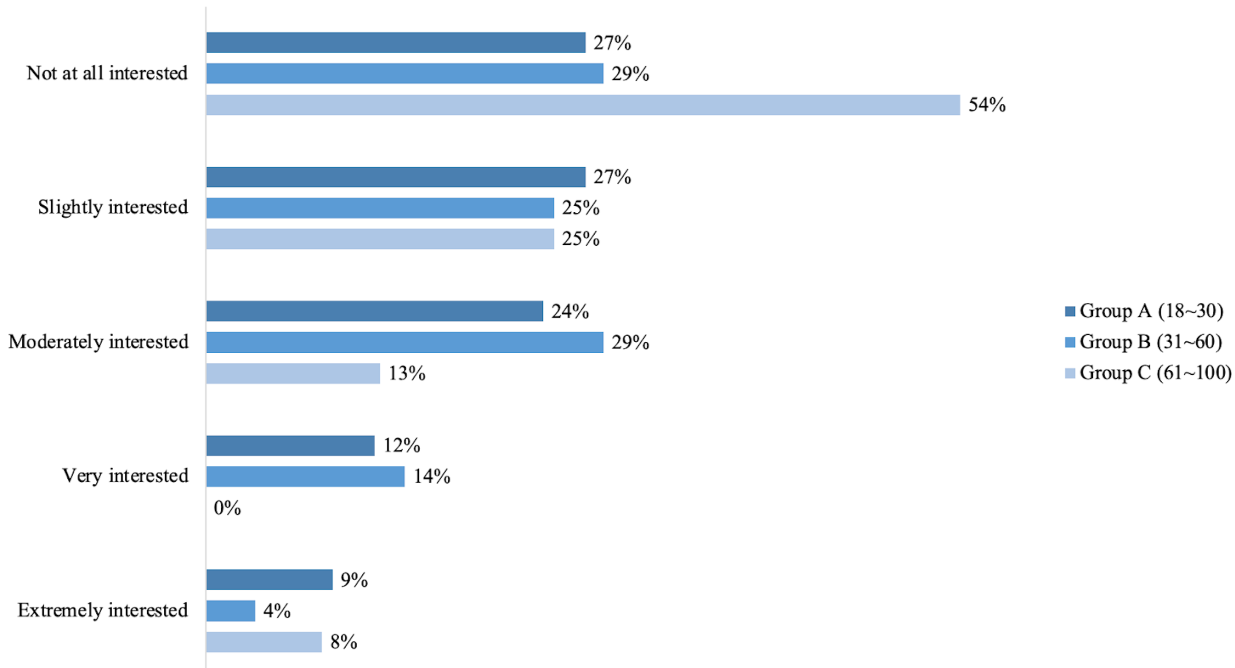
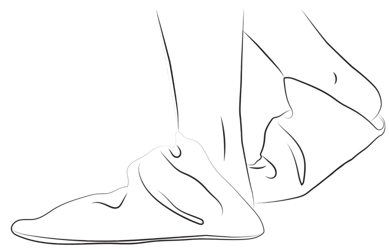


Table J.6. Anonymous participants' feedback for concept 5

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• The design makes me feel comfortable.	• The design is too complicated. • Mobile phone control can cause issues around memory and management. • I really don't like the thing between my toes. • How will this keep my feet warm in the winter? Can I wear them with socks?	• Wonderful solution. • Not so necessary design. • This is not a great design for older feet with deformed toes and fragile bones. • Never a flip flop for oldies. We will flip then flop. • I don't like sandals and this style of shoes.

Concept 6



Concept description

Even though this ice-cream-cone-shaped indoor footwear is designed without full heel support, it is designed to make people feel very comfortable walking without shoes. It is composed of one piece of smart fabric embedded with high-tech sensors.

Figure J.6. Participants' interests level towards concept 6

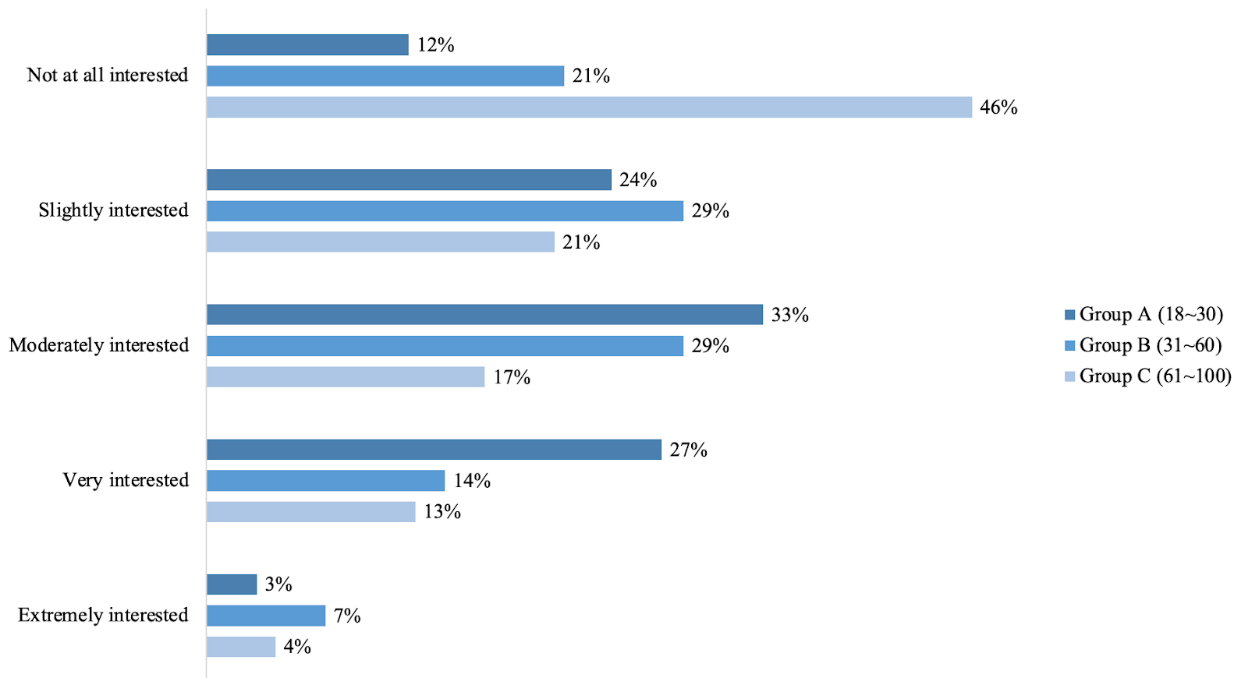


Table J.7. Anonymous participants' feedback for concept 6

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• It feels like you are walking while putting on half socks on your feet. • Hopefully, when you walk, your feet won't feel hard or painful when you step on the ground • This is a creative solution. • It appears to be easy to fall off when walking.	• It depends on the functions. • Too thin in terms of shoe structure. It looks very special. • Don't want to have an unnecessary design. • It can wrap feet closely to prevent the shoe from slipping off the foot. • I think that they would fall off my feet while walking. • Focus on the comfort part.	• I have three concerns: support, protection, and safety. • I prefer to have heel support. • I feel there is not enough support for me. • Even though it looks comfortable, is it safe? Can it slip off?

Concept 7

Concept description

The indoor footwear is designed with an air-supported shoe sole and other smart sensors to adjust people's feet ergonomically. Its structure makes people feel like they are delightfully walking on air.

Figure J.7. Participants' interests level towards concept 7

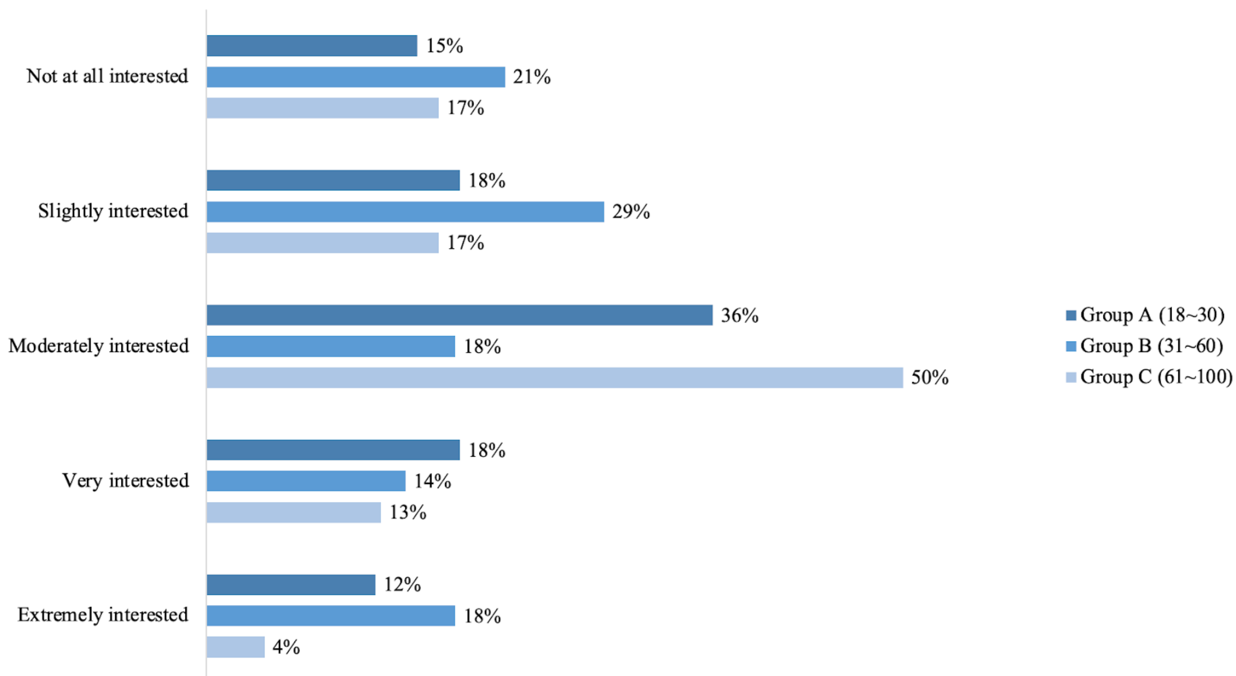


Table J.8. Anonymous participants' feedback for concept 7

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• Too bulky as indoor footwear • The structure looks a little bit complicated; I'm looking forward to experiencing the contrast it gives me. • It looks more like an outdoor footwear design. I may wear it outdoors.	• I feel the design is hard to fit in the indoor environment. It feels too heavy in terms of design language. • This is the most attractive design to me among others. • The choice of indoor footwear material is the key. • People with enough weight will feel better, otherwise foam will be more suitable.	• I would want a back strap and room for socks for warmth. • These shoes look good, but I don't understand the technology part. • People's indoor activities involve less walking than outdoors. This may not be so necessary. • I feel the design does not support the entire foot enough. • Lovely but open-toed design can be a problem for older adults.

Concept 8

Concept description

The indoor footwear has two parts to be tied to people's feet with minimal surfaces: instep support strip and toe thumb. It provides the maximum space to let people's feet breathe and relax.

Figure J.8. Participants' interests level towards concept 8

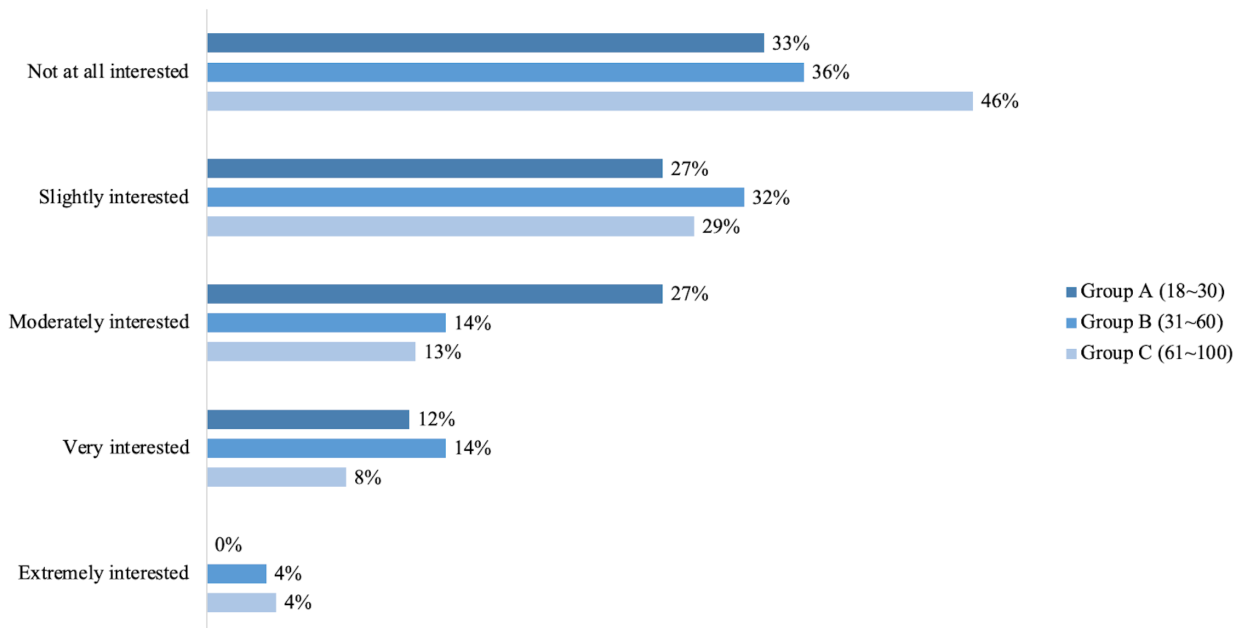
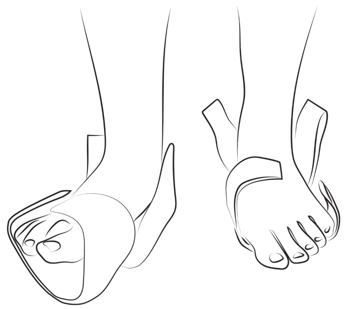


Table J.9. Anonymous participants' feedback for concept 8

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• I don't think a design that ties to people's feet with minimal surfaces is the most comfortable. • It is a cool concept but the design is for the winter season. • I feel the design is not that comfortable.	• Does the design consider the scenario in winter? • It feels like an outdoor footwear design. • There is a conflict between this scheme and the overall design. • It looks comfortable, but not that convenient.	• I would never wear shoes with toe straps. • The design makes me feel it lacks protection and support. • I was concerned that the design might not stay on people's feet. • It makes cold feet in winter.

Concept 9



Concept description

The indoor footwear will automatically attach and adapt to people's feet once it detects people's weight and the shape of their feet.

Figure J.9. Participants' interests level towards concept 9

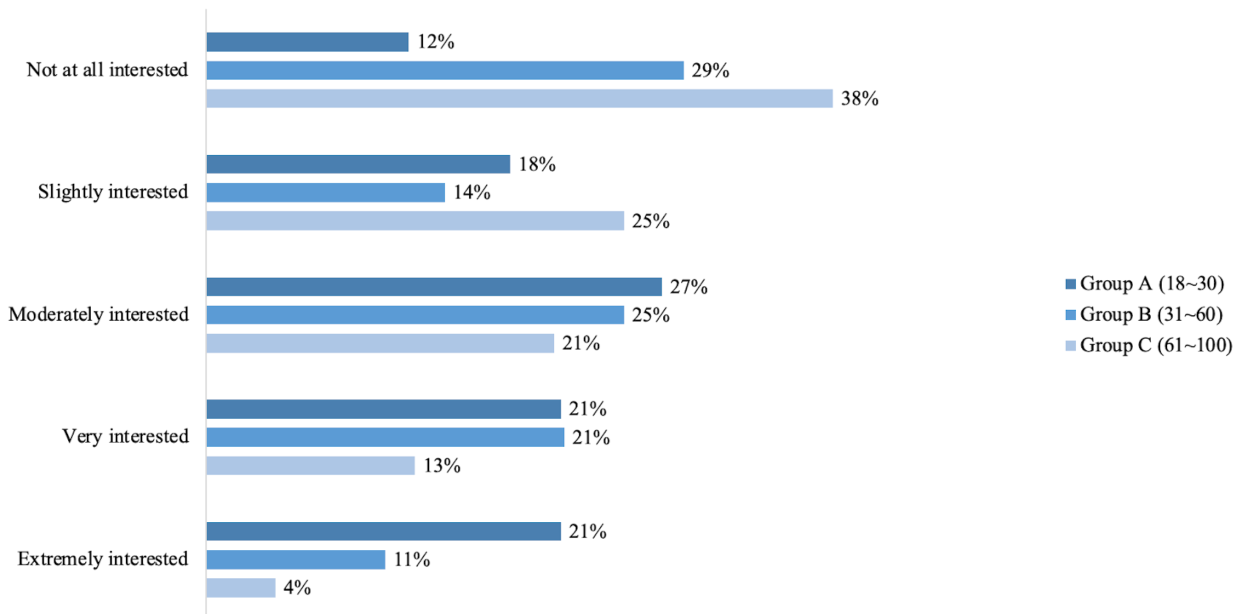


Table J.10. Anonymous participants' feedback for concept 9

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• The concept is definitely designed for lazy people. I am 100% the target user. • Hope the design can help people wear and take off automatically. • It might be good for frequent travelers. • It's a very futuristic design. • It is hard to pile up in the shoe closet.	• For a typical shoe design, this concept is a bit complex. • I don't feel secure, especially because I feel the shoes will be fall offeasily. • It seems like a high-tech design and I'm intrigued. • It looks very comfortable. • It is critical to choose the right material with memory function.	• It is an interesting creative idea, but what about adjustments for uneven leg length, etc. - heel inserts? • I like this idea but the sole doesn't seem sturdy and I feel it has too little support for my feet. • I am concerned about the foot protection. although it is a good design for the elderly.

Concept 10

Concept description
The indoor footwear will generally adapt to its friction level through smart material texture according to the size of people's feet and their walking pattern.

Figure J.10. Participants' interests level towards concept 10

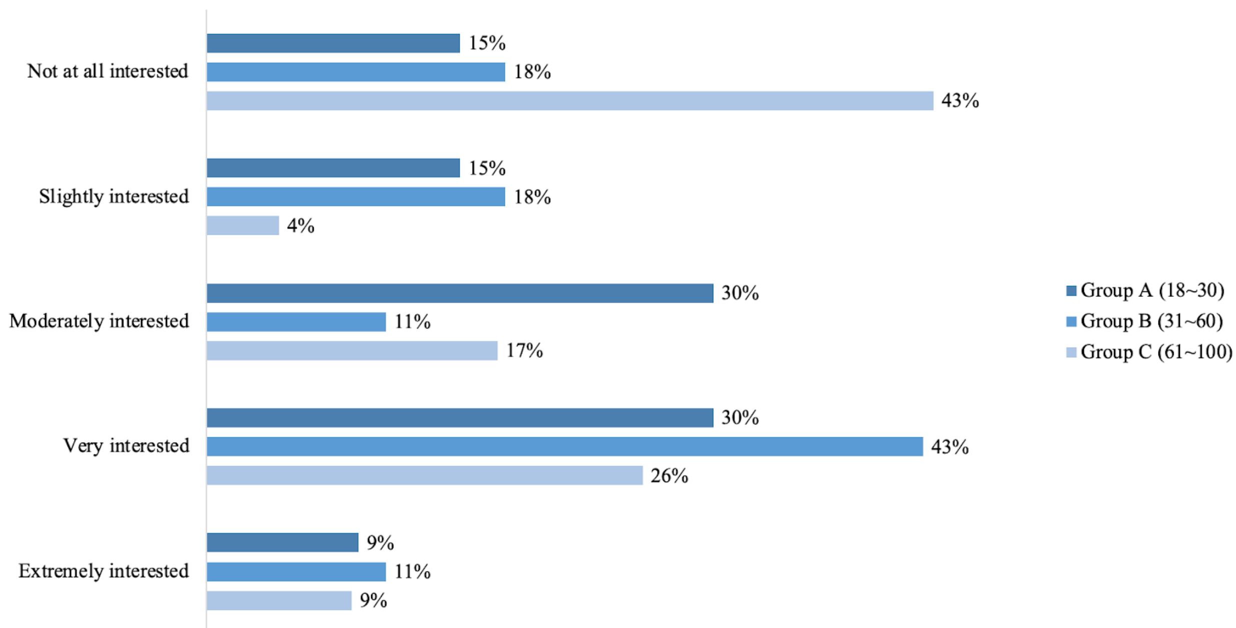


Table J.11. Anonymous participants' feedback for concept 10

Group A (ages 18~30)	Group B (ages 31~60)	Group C (ages 61~100)
• This is a high-end product since the design considers the details such as friction. • Friction is a critical factor to consider, especially when we consider the indoor environment. • I am worried about the shoe falling off or slipping off suddenly from my feet. • It is a very cool design concept.	• It seems cool, but it lacks security. • It can prevent serious deformation of the diagonal. • It looks like the design is inspired by a lotus leaf. • I think it would be a novel experience for customers.	• Not slippery when in water surfaces • I have Peripheral Arterial Sclerosis . . . and need to know when potentially dangerous friction occurs • I am curious how they stay on my feet? • Fascinating….and how is the foot supported and protected?

Appendix K—Hybrid Participatory Workshop Pre-workshop Survey

Hello, my friend,
Welcome on board! We are so glad to have you with us to join an exciting and adventurous design journey. Before we start our design journey: hybrid participatory workshop, we need you to fill out the quick pre-survey questions in order to help us design a better, immersive, and tailor-made online workshop experience for you.

Thank you for your great help and we look forward to seeing you soon!

Your workshop coaches and mentors,
Sheng-Hung Lee, Ziyuan Zhu, and -ing Creatives Team

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1. People — We want to know you and make friends with you.

Question 1.1.
Your Name: ____________________

Question 1.2.
Your Email: ____________________

Question 1.3.
Your Phone: ____________________

Question 1.4.
Age

○ 10~20

○ 21~30

○ 31~40

○ 41~50

Question 1.5.
Gender

- ○ Male
- ○ Female
- ○ Prefer not to say

Question 1.6.
Country of Residence: ______________________________

Question 1.7.
Occupation: ______________________________

Question 1.8.
LinkedIn Handle/Account: ______________________________

Question 1.9.
Instagram Handle/Account: ______________________________

Question 1.10
What drives you to participate in our online co-creating workshop? (100 words)

____

Question 1.11.
How do you know about the workshop?

- ☐ ING Creative Website
- ☐ Social Media
- ☐ Friends Recommend
- ☐ Other

2. Purpose — We want to understand why you are interested in the IoT product.

Question 2.1.
Given the various levels of automation that smart (IoT) wearable devices can have, what level of automation would you be comfortable with your smart (IoT) wearable devices?

The device needs to be set up before people use it. It follows the fixed program.	1	2	3	4	5	The device treats me as my close friends that understand and can predict my next step.
	○	○	○	○	○	

Question 2.2.
How comfortable are you in sharing your data on the cloud when using smart (IoT) wearable devices?

The device won't store any of my personal data.	1	2	3	4	5	I am willing to share my data on the cloud with the community.
	○	○	○	○	○	

Question 2.3.
Design with data is like (please complete the sentence)

Question 2.4.
If you had a pair of smart indoor footwear, what functions would you want the footwear to have? (multiple choice)

- ☐ Help me to exercise
- ☐ Help detect and collect information about my health condition(s) (e.g., blood pressure, pulse, gait)
- ☐ Control my home appliance(s)
- ☐ Communicate with other people
- ☐ Track my indoor trajectory
- ☐ Serve as a personal assistant
- ☐ Help me relax
- ☐ Others

Question 2.5.

Which of the following functions would you want IoT wearable devices (not just a pair of smart indoor footwear) to help you with? (multiple choice)

- ☐ Improve my work efficiency
- ☐ Increase my creativity
- ☐ Optimize my time
- ☐ Make my life convenient
- ☐ Connect with other people
- ☐ Others

3. Prototype — We want to hear your story about making and design.

Question 3.1.

Your design level?

Beginner	1	2	3	4	5	Professional
	○	○	○	○	○	

Question 3.2.

What type of designer you are?

- ☐ Architect
- ☐ Product Designer
- ☐ Service Designer
- ☐ Business Designer
- ☐ Organization Designer
- ☐ I am not a designer
- ☐ Other

Question 3.3.

Any questions you want to ask us?

Appendix L—Hybrid Participatory Workshop Post-workshop Survey

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Hello, my friend,
Thank you for participating in our hybrid participatory workshop last week. We want to hear from you about suggestions on making our future workshop more engaging and meaningful.

Thank you for your great help and we look forward to seeing you soon next time!

Your workshop coaches and mentors,
Sheng-Hung Lee, Ziyuan Zhu, and -ing Creatives Team

Question 1.
Your Name: ____

Question 2.
Your Email: ____

Question 3.
How do you feel about the workshop in general?

- ○ I am not the right audience of the workshop.
- ○ I am not that interested in the topic and content.
- ○ I feel it's OK and no strong preference.
- ○ I like it but I know most content and skills.
- ○ I love it and it went beyond my expectation.

Question 4.
How difficult do you think the workshop content is?

- ○ The workshop content is too simple to me.
- ○ The workshop content is relatively easy to understand.
- ○ The workshop content is OK to me.
- ○ The workshop content is a bit hard to me.
- ○ The workshop content is very difficult to me.

Question 5.
Describe your workshop experience in terms of feeling in three keywords.

Question 6.
If there is an advanced version of the workshop (with electronic components), how would you like to attend it?

- ○ The advanced version workshop is no attractive to me.
- ○ The advanced version workshop is a little bit attractive to me.
- ○ The advanced version workshop is OK to me.
- ○ The advanced version workshop is attractive to me.
- ○ The advanced version workshop is very attractive to me.

Question 7.
How long do you think is proper for the online workshop?

- ○ less than two hours
- ○ Two hours
- ○ Three hours
- ○ Four hours
- ○ More than four hours

Question 8.
Things you want to learn more from the workshop

- ☐ Design process
- ☐ Prototype methods
- ☐ Ideation
- ☐ Design research
- ☐ Case study
- ☐ Business side of design
- ☐ Product design
- ☐ IoT-related topic
- ☐ Others

Question 9.
Upload your prototype photos from the workshop if you want to share them with us

___

Question 10.
Any other comments & feedback you want to share with us?

___