

Sunflower: A Tactile Navigation System for Low-Vision Environments

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Abstract

Sunflower: A Tactile Navigation System for Low-Vision Environments

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In navigating 3D space, we typically use vision more than any other sense. To see a space is usually the quickest way to orient ourselves and reach our destination. However, there are times in which our vision is too impaired for optical understanding of a space.

This is a conceptual exploration of tactile navigation in low-vision scenarios—particularly high-stress, high-stimuli, or complicated environments—through the use of a wearable sensor mesh network called Sunflower. It is targeted at individuals such as firefighters, parents of young children, and directionally-challenged individuals who regularly deal with these situations.



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SUNFLOWER

A Tactile Navigation System for Low-Vision Environments

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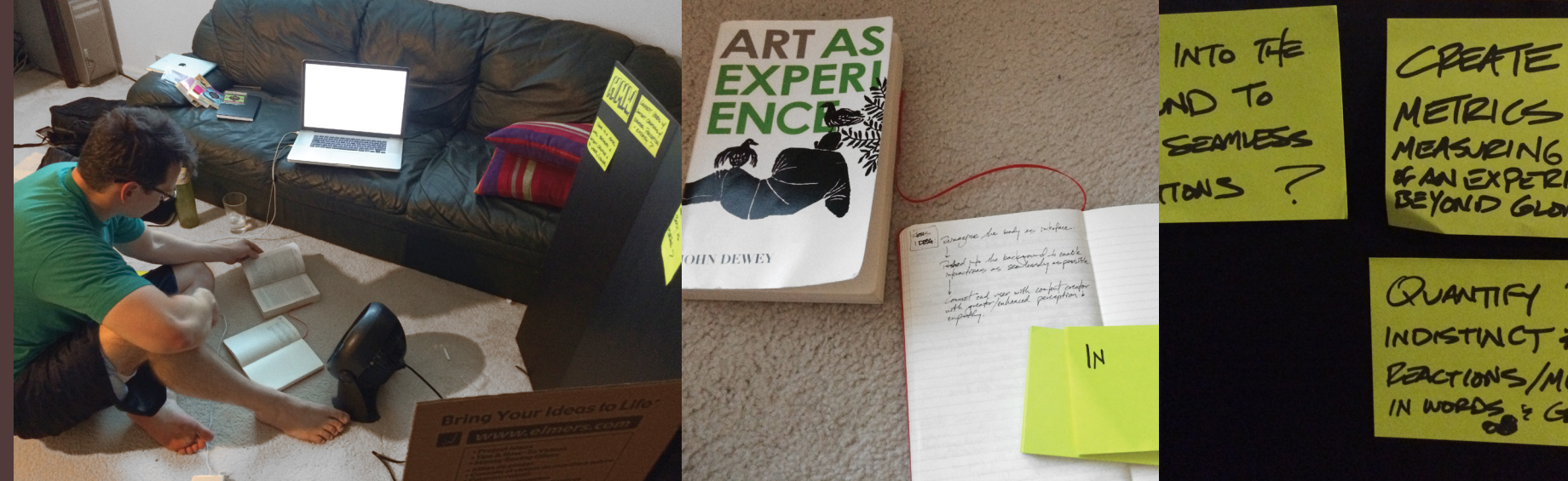


How Might We Feel 3D Space?

In navigating 3D space, we typically use vision more than any other sense. To see a space is usually the quickest way to orient ourselves and reach our destination. However, there are times in which our vision is too impaired for optical understanding of a space.

*This is a conceptual exploration
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vision scenarios*

—particularly high-stress, high-stimuli, or complicated environments—through the use of a wearable sensor mesh network called Sunflower. It is targeted at individuals such as firefighters, parents of young children, and directionally-challenged individuals who regularly deal with these situations.



Essentially we are asking, how might we replace sight with touch? Can we replace one sense with another? Each of our senses flourish in certain situations and are ill-suited for others. Our sense of touch, or feel, is best in close proximity when we are “aware of something that affects us physically, such as pain, heat, or an object touching our body.”¹ Typically we associate feeling with tangible objects, and physical sensations or emotions. Yet 3D space is, by definition, empty.² There are things within the emptiness that we need to interact with, understand, find or avoid and sight is the sense best-suited for detecting those things, because it happens at a distance. We can be far away and see what is in a space.

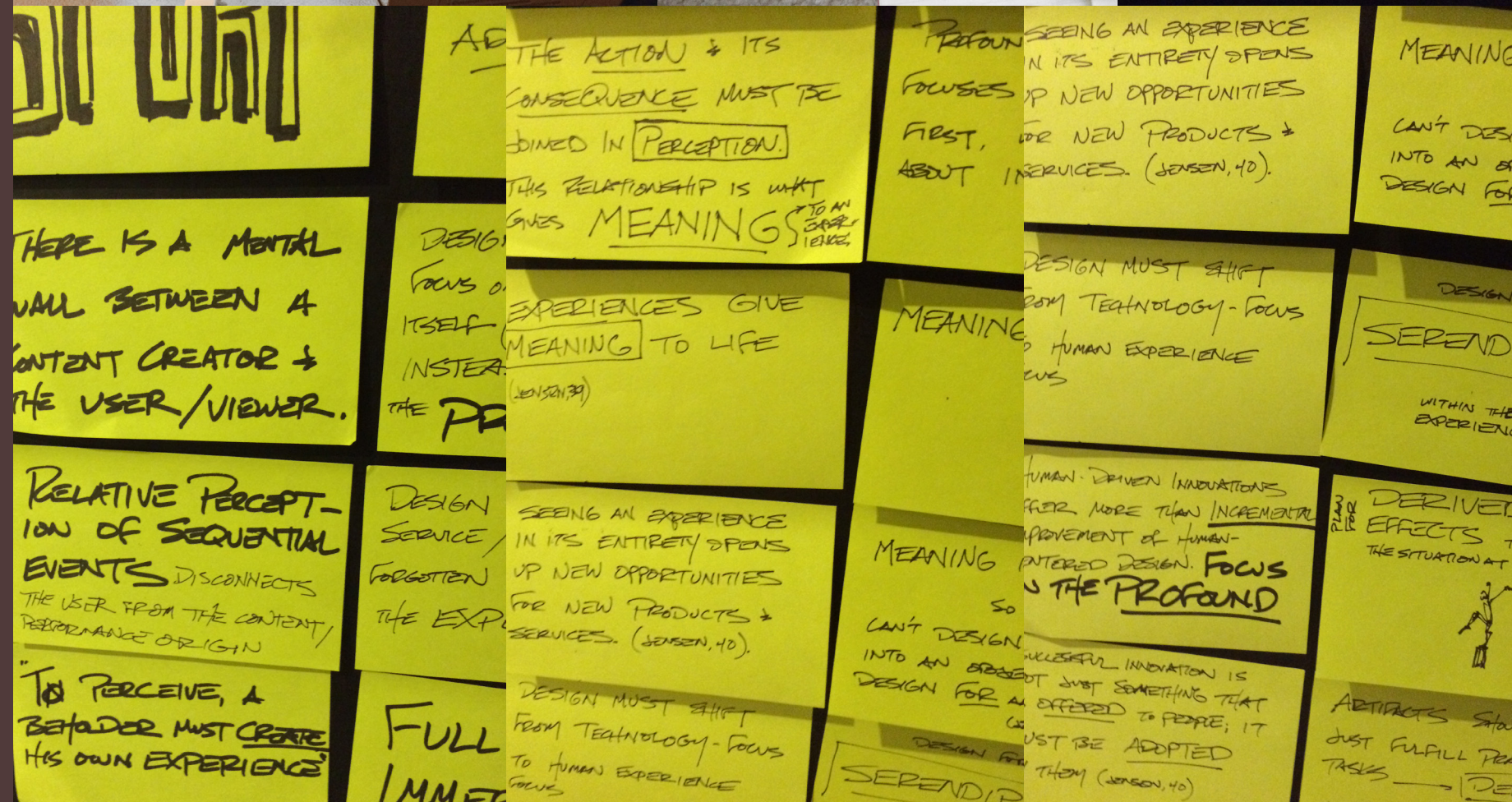
However, if sight is removed, waiting for contact may take too long, or be too dangerous, especially in scenarios like those listed above. We need to be able to step back, and determine what is in a space in a meaningful way, without being able to see it. Therefore, what we are really asking is how might we feel something we cannot actually feel? And, furthermore, how might we develop a product in this space that could feasibly be adopted for use in the real world?

What we are really asking is, how might we feel something we cannot actually feel?

To begin exploring this question, I started with the tried and true method of Sharpie and Post-Its to organize an initial visual story of design philosophy and rough ideas that would drive my research and design. Working in small analog spaces forced me to keep my distance from any technological or aesthetic considerations. At this early stage, the story simply focused on best practice philosophies for designing a meaningful product-user relationship from the ground up in two main problem spaces:

1_ Low-vision navigation

2_ Wearables



Low-Vision Navigation

Low-vision navigation is the first lens through which to address the question of feeling 3D space. In our day, navigation has been greatly enhanced by the revolutionary achievement of global positioning technology (GPS). GPS has enabled us to get to unknown destinations more easily and accurately than pre-mobile-device generations ever imagined. It has solved many of our navigation issues, but currently, it is limited to the outdoors. GPS can get one to a building, but it cannot get one around inside it. Furthermore, there are aspects of it that cause confusion, endanger our lives, and make us dependent upon our phones, even when the situation demands the attention of our eyes and hands.

We live in a three-dimensional world, and naturally perceive distance and direction relative to our physical location. We can see a landmark with our eyes and estimate about how long it will take to arrive there at our current pace, innately sensing if we need to speed up or slow down. Yet, we do not know with complete accuracy what a specific number such as “350 feet” actually looks like. When that number coincides with an unknown street we are rapidly approaching, it lowers our confidence that we will be able to turn at the exact spot on the first try. This limits GPS applications such as Google Maps or Apple Maps in their ability to convey a sense of 3D spatial location on a 2D screen.

Might we compensate by substituting our innate spatial senses for the verbal and visual directions served up by those apps? Is it possible to instead feel what it means to “turn right” or “head straight for 350 feet” without a screen? How might we tap into the body’s innate sense of spatial comprehension?

Feeling the directions would free our eyes for when they are needed elsewhere. In the car or on a bike, screens become a liability and lead to distracted driving, as shown by the 9 deaths per day of screen-related car accidents in the U.S. alone in 2014.³ Our eyes, and either our hands or voice, are usually required to plot a destina-

tion. But distractions abound as we look away from the road to the screen to verify our course is correct. These simultaneous requirements of forward movement and eyes both on the road and screen are major issues for smart device navigation today.

As dangerous as is road and screen combined, let us go a step beyond and consider what happens if we cannot see at all. These situations frequently arise for many who are not even visually-impaired. For example, firefighters, parents of children lost in a crowd, or new students on a complicated campus must routinely deal with low-vision, high-stress situations. These individuals require eyes and hands for more than merely using a smartphone.

Because eyes- and hands-free is not an option for this problem space, we need to find a system that can feedback information to us in a way that we would normally function, and enhance our existing capabilities without breaking stride. What tools or systems might allow us to navigate these scenarios naturally, without the use of eyes or hands? It seems most logical that within the next ten years, the answer would probably come in the form of a wearable device.





Introduction: Problem Space #02_Wearables

Wearables

Over the next decade it is inevitable that wearable sensing technology will become more and more pervasive. A quick glance at Engadget, Gigaom, or CES reveals new wearable startups and products almost daily. Academic journals are full of contraptions mounted on the head, waist, arms, and everywhere else. Although the devices are plentiful and varied, we can mostly distill them into two separate and, surprisingly, clean-cut categories:

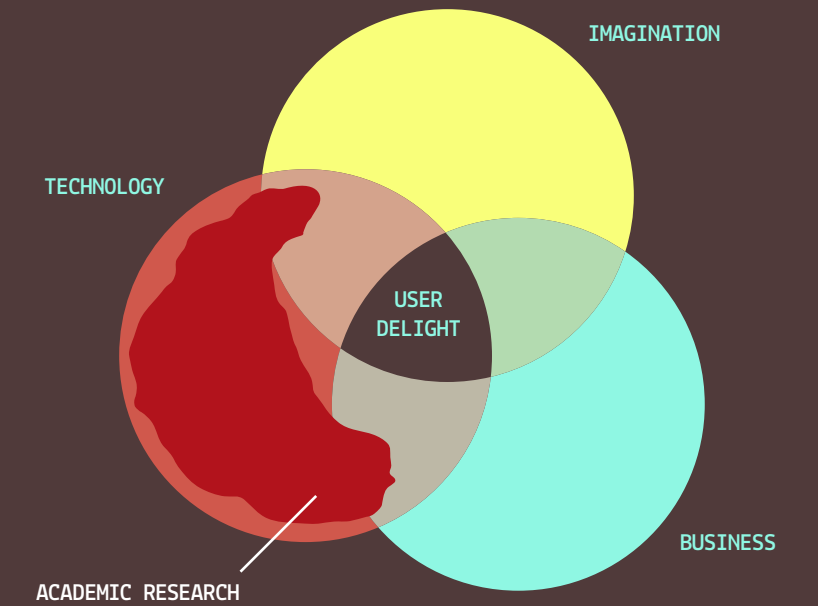
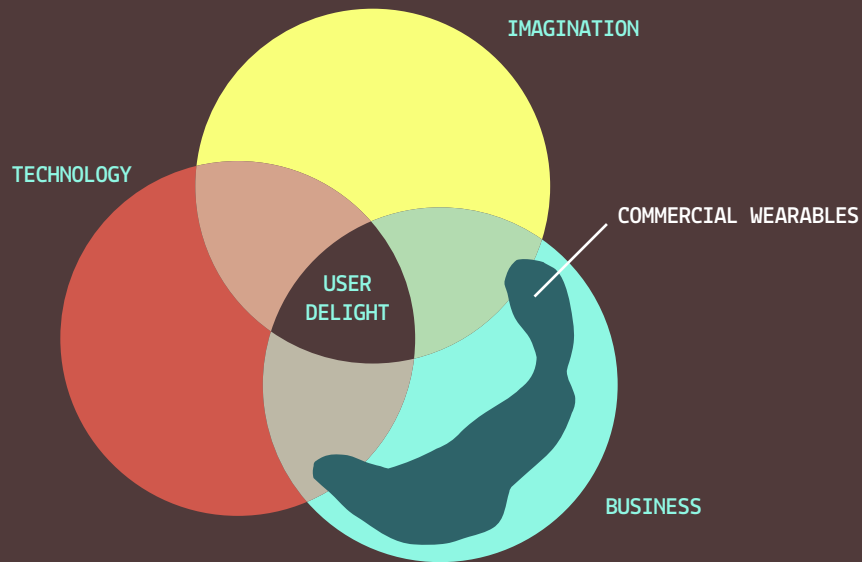
1_ Extremely limited commercial products

2_ Clunky and unusable scientific projects

On the commercial side we have a plethora of shirts from companies such as Ralph Lauren,⁴ Hexoskin,⁵ and Under Armour,⁶ as well as watches,⁷ belt buckles,⁸ socks,⁹ and headphones¹⁰ that do little more than track movement and basic biometrics such as heart rate, breathing rate, activity levels, sleep, and so on. These are valuable functions that can do much to recommend ways to improve overall general health and help athletic training. But they are limited to the few bio measurements that we can currently make non-invasively.

This limitation of data usually restricts the devices to a single pathway of interaction with the user. They gather information and display the data back to the user in a digestible format, but the soliloquy hardly develops into dialog. The user is free to act on the data, but the interaction pathway is dropped without notable impact on the user's next steps.

Take Fitbit for example. It is a wearable device that tracks various biometric and activity data such as amount of exercise, activity, and sleep. It takes this data (such as steps taken or heart rate) and works with data manually entered in such as weight, food eaten, and exercise done to set goals for the user to work toward. Many have testified of the benefits they have received from such tracking and enthusiastically talk about how inspired they are. In fact, "inspire" is one of Fitbit's key value propositions. The idea is to motivate people to take a proactive stance toward their personal health. This is commendable and something that we all should do. Freedom is an innate desire of all people, and there is a balance of how far a device should go in prescribing next steps. We certainly do not want to give all of our decision making over to machines. Yet, Fitbit feels as if it falls a bit short of its potential for impact on lives— even a bit superfluous. All it is doing is showing basic data. The rest is up to you. There seems to be a large opportunity space here for greater impact and well-being.

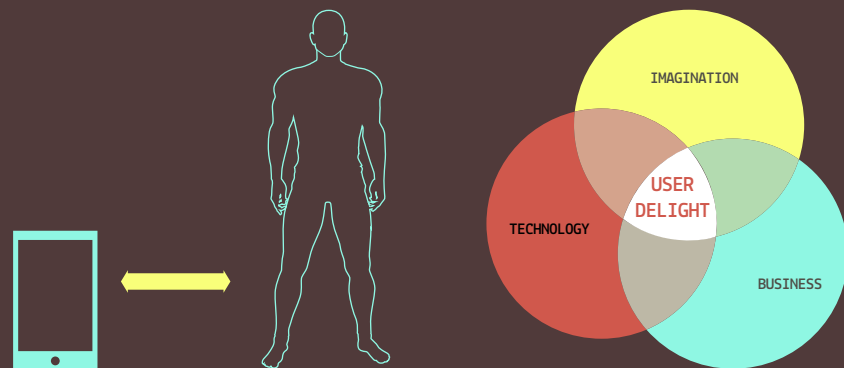


In the world of academia and commercial research we find a slightly different story: items heavy on the sensing and feedback side, but light on the user case and business side.¹¹ These projects reveal an abundance of scientific breakthroughs that focus solely on raw technological development. Because of the mechanical problem-solving focus of the work being done, the usability of the product is rarely considered. For example, bulky head-mounted cameras and displays frequently work together with unwieldy belts, vests, jackets, or shoes full of sensors and vibrating buzzers to test new algorithms and systems.

One such project is called Tyflos.¹² Dakopoulos, et al created a system that aids navigation through two cameras attached to dark glasses, a microphone, an ear speaker, and a vest containing an array of vibrating motors attached to a portable computer. The project is focused mostly on the modeling and implementation of the vibration array language and hardware module. It reads images of the surrounding environment and downsamples them into depth maps to activate the vibrating array. Areas that are open and pose no obstacle threat to the user are read as black, while obstacles that could prevent movement are read as gray to white, which activate the vibrators accordingly.

Although the project had some difficulties with the results, the idea is a fine one, and could perhaps become a viable product with the right vision of how to implement it. However, no one in their right mind would actually purchase such a contraption in its current state, let alone actually use it in everyday life. That was obviously not Dakopoulos, et al's intention for this. In these embryonic stages of development, where scientists are focused on making new technology exist, it is not reasonable to consider end users.

That is a focus for later. But it is an extremely important focus that must be addressed at least some time within the development cycle. The true mark of a successful wearable device is not necessarily measured in what it can mechanically achieve, but rather, one that works in dialogue of input and output between the device and user.¹³



What does this dialog look like? The device gathers data, presents it to the user, prescribes specific actions, and influences the user's next steps. The user reacts by altering behavior, and presenting the changes to the device for an assessment. The system then gathers more data on this state change, presents, prescribes, and influences yet again, thus engaging in a dialogue between user and wearable, rather than the all-too-common wearable monologue.

This two-way conversation between device and user is what gives the product meaning and makes it significantly more likely to be adopted by the public. This two-way conversation rarely happens by technological advancement alone. It requires an understanding of the potential target user combined with imagination of uses and interactions with the technology to make that happen. And when it does, we get a fulfilled Venn diagram with a three-way intersection of an identified consumer market, advanced technology, and imagination that delights the user. This is why at some point we must consider the actual integration of new technology into everyday human lives.



Product

User

Good designers are adept at both considering target users and imagining possibilities. Due to the latent needs of users, as well as the non-linear pathway to combining technology with imagination, achieving this two-way conversation can often be an ambiguous challenge. The process for developing product-user dialog is often referred to as *human-centered design*, or *design thinking*.¹⁴ According to IDEO's Tom and David Kelley, design thinking is ideal for problems that cannot be "easily analyzed."¹⁵ Generally, in design thinking, a design team takes a lightly-defined, but still unclear problem space with solid goals such as *Client wants to build financial literacy among inner-city youth*, *Client wants to increase parent involvement during early childhood development*, or, *Client wants release a new model of car stereo*. To find the best way to achieve these goals, the designers first seek to understand the problem space as quickly as possible within the

(usually ultra-short) project timeline. By first gaining empathy for the end user through ethnographic study of people in their natural settings, asking questions, and recording what they observed, designers can get a quick birds-eye view of the problem. Next they attempt to "move past concrete observations to more abstract truths" by synthesizing their observations.¹⁶ This allows them to find what the Kelley Brothers call "the fertile ground" for innovation.¹⁷

Once this fertile ground is identified, ideation and prototyping begin. Ideas are rapidly developed through sketches, rough physical or 3D models, or anything else that will make the idea tangible. This allows it to be commented on, tested, and refined; the quicker and dirtier the prototype, the better. All of this effort prepares a road map for a successful product launch and ability to thereafter thrive in the world.¹⁸

The Design Process

Step 01 Project Initialization

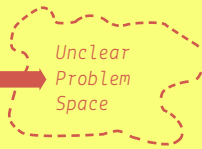


Client wants to build financial literacy among inner-city youth.



But what does this mean? How does one achieve this?

Step 02 Problem Empathy



Designer observes inner-city youth in their environment to understand the problem space.

Step 03 Observation Synthesis



Fertile Ground



General Truths

Designer extracts general truths from specific observations to find the "fertile ground" for innovation.

Step 04 Ideation & Prototyping



Fertile Ground

Work to make ideas within fertile ground tangible so team and client can comment and test.



This sort of ethnographic design research is excellent for existing products' next-generation iterations. Clients often ask, *What's next?* without obvious next steps.

- *This car needs to change, but how?*
- *Millennials are not using our checking service. Why?*
- *Our product is in danger of becoming stale. How do we prevent that?*

Human-centered design finds out first-hand what target users want and need, and then imagines possible next steps within the fertile ground of each problem space. Take for instance, the LG washing machine displayed at CES 2015 that has a "baby" washing machine underneath a large one.¹⁹ This is the classic type of incremental innovation that is probably based upon some sort of insight derived from human-centered user research. Researchers from an external design consultancy probably visited multiple homes, watched people doing laundry, saw several people having trouble separating their intimates from darks and denims, and identified it as a pain point. Then they likely began design iterations around it, first divergently, then convergently, and made a report to LG of what they saw, along with recommendations to alleviate this pain point. This presumably went into iteration cycles of sketching, modeling, prototyping, and testing until this new "almost-double" laundry offering resembled what was presented at CES. At times, this design process is very clear cut and easy to reverse engineer.

Atypical Ambiguous Situations

But what about situations in which we know we need a new product, but nothing exists to build upon? The 1960s space program, as documented on the Science Channel's "Moon Machines" was just such an occasion.²⁰ NASA needed to develop things like survival gear for astronauts, but no one had ever been to the moon before. How would they even know what deliverables to aim for? What should the unnamed items be? What should they do? What forms should they take?

J. Chris Jones identified this very issue in 1970 when he posited that the very nature of design is working backwards in time before an intended artifact exists:

"The fundamental problem is that designers are obliged to use current information to predict a future state that will not come about unless their predictions are correct. The final outcome of designing has to be assumed before the means of achieving it can be explored: the designers have to work backwards in time from an assumed effect upon the world to the beginning of a chain of events that will bring the effect about."²¹

*Actual design prototype from 1956.²²



HERE'S WHAT WE'LL WEAR

Designers are already working on the styles the well-dressed space man needs to survive.

Emergency pressure cell designed to provide crew members with individual atmosphere if ship leaks.

Christopher Alexander cynically lamented how the complexity of these problems is often far beyond the capability of man to master, leaving him utterly defeated.²³ He even went so far, in fact, as to suggest that mankind would have been better off had no designer ever gotten involved in the first place. He makes a good point. There are definitely problems that seem too far beyond the scope of man's ability to conquer, such as urban planning, as Alexander specifically referred to. Some issues indeed seem to get worse the more with which they are tinkered. However, as the cheerful title of this thesis suggests, I do not subscribe to defeat by complexity, or the untestable. I prefer a bit more of an optimistic mental outlook. Just as NASA eventually found the solution to preserve life in outer space through imagination and technological development, I believe we have the power to achieve anything, provided we have enough imagination to guide our development. In situations like these with no obvious steps or existing technology, we need to start at the beginning of the problem, unencumbered by technical details. When those boundaries are removed, the mind is free to consider a myriad of possibilities, which, in turn, facilitate the generation of an unconventional future vision. We imagine what it might look like if this problem were solved in the ways we desire without worrying about how to get there

technologically. If the vision is inspiring, yet plausible, it will facilitate discussion, ideation, and eventually, prototyping, testing, and reiteration to turn that vision into reality.

Low-vision navigation is a problem in need of such a vision, much like that of 1960s outer space survival. We have identified an issue without complete understanding and nothing currently exists that is remotely close to solving it. The potential solution could be one of many options, most of which are beyond our current state of technological advancement. Considering it is probably something that will be best solved with technologies that no one has at the moment, how should we proceed?

There are several groups trying to tackle this low-vision issue in regards to firefighters, including the Worcester Polytechnic Institute (WPI),²⁴ Homeland Security Advanced Research Projects Agency (HSARPA),²⁵ and the German Federal Ministry of Education and Research (BMBF).²⁶ Each group has run into varying amounts of success, but no one has yet completely solved the problem. Due to the practical need to find an immediate solution, each mostly focused on current technologies that exist today. But in order to create a profound user experience with the much-coveted product-user dialog discussed above, we must consider what would be best for the user regardless of technological constraints.

Therefore, for this problem space of low-vision navigation, I am suggesting a shift in approach from a technological to a human experience focus.²⁷

Obviously this shift in emphasis is the point of human-centered design. HCD methodology typically requires an ethnographic study of the subject complete with expert interviews, direct observations, or other research methods in order to begin attacking the problem. However, based on the lack of success of the aforementioned research groups, it is very likely that the best option may require technology that does not yet exist. Figuratively speaking, there are no spacesuits for us to observe and test. Therefore, it may be beneficial to step back, look at the problem with a wider lens and higher altitude, and focus more on generating a plausible vision. Once a vision is established, we can test certain parts of it with analog mock ups to see if they are viable before too much capital, time, and effort are expended.

In order to draw up a plausible conceptualization of low-vision navigation, I will explore it from three different scenarios:

1_ Firefighters in burning buildings

2_ Families in crowded public places

3_ Students on complicated campuses

I chose these diverse scenarios because they highlight very different aspects of why we use our eyes, and explore what happens when we cannot see and need to find another way. Ideally, this exploration will establish a vision to help coordinate the efforts of scientists, researchers, and designers to respond to this problem in the future.

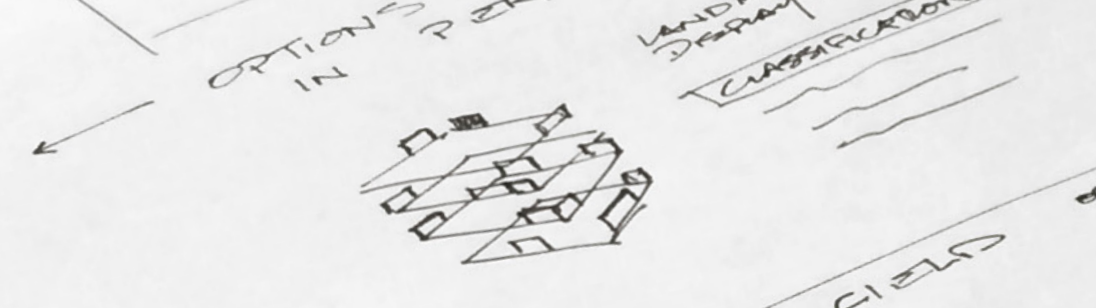
PART

02

Research & Ideation

30

How do we treat
North/South orientation
w/ the 3D map?



FIELDS OF VIEW

SHOW LIST THESE IN AN ORDER THAT ALLOWS
WATERFALL FILTERING — I.E. EACH SELECTION
NARROWS AVAILABLE OPTIONS IN THE NEXT COLUMN.

CLASSIFICATIONS
(I ONLY WANT THIS
TYPE OF STORE)

RATING
(ABOVE A
4-STAR)

PROXIMITY
(THAT ARE WITHIN
50 FEET)

NAME
(SO ONLY
NAMES SHOW UP)



LASIDE MENU TO RB

Literature Review

No vision should ever be blindly established. To proceed, I first set out to understand what has been done in the low-vision navigation and wearable problem spaces, as well as the underlying principles of perception and tactile sense. My academic journal literature review revealed it to be a busy space. Thus far I have searched databases of both IEEE and ACM Digital Library using the terms “spatial navigation” and “wearable navigation.” The volume of results was predictably overwhelming, with 11,156 returns

combined. I narrowed the results by focusing on actual experiments, rather than sifting through all the technical algorithm-based articles, as I was not trying to become an expert in this field at this point. I then limited the time to the past three years, back to 2011. It seemed reasonable that the major experiments conducted before that time would be referenced by someone over the past three years. My filters narrowed down the results to 126 total articles.

11,156

Returned Results

reduced to

155

Usable Results

Step 01

Terms Used:

“spatial navigation”

“wearable navigation”



Step 02

IEEE Xplore Digital Library (2264 Results)

ACM Digital Library (8892 Results)



Step 03

New Terms Used:

“indoor spatial navigation”

“wearable navigation”



Step 04

IEEE Xplore Digital Library (152 Results)

ACM Digital Library (970 Results)



Step 05

Filtered by title and abstract; eliminated most technical “how-tos.”

Focused on method applications and usage experiments.



Step 06

IEEE Xplore Digital Library

ACM Digital Library

29 Results

126 Results

Searched databases of IEEE and ACM with terms “spatial navigation” and “wearable navigation.” Manually filtered from 11,156 results to 155 articles for use in the ground-work of this thesis.



I repeated the search for the term “firefighter,” which returned 400 results in ACM. That was too many so I narrowed the search term to “firefighter position,” which brought back 191 results. I sorted by title and abstract to eliminate “virtual environment,” “simulation,” articles, and articles not directly related to indoor positioning/navigation for firefighters. This allowed me to focus on 24 articles about firefighting and positioning.

These articles detail numerous experiments with actuators on belts, vests, gloves, canes, or other items designed to buzz in the direction the user should go.^{28, 29, 30} Many have looked into virtual reality,^{31, 32} as well as body-mounted cameras.^{33, 34} There have been attempts to map the most ideal spots on the body for a universal guideline declaration to ensure fit and comfort.³⁵ Some have developed virtual reality concepts in which a single place was pre-mapped to goggles or a personal projector to lead the user.³⁶ Others have placed vibration arrays

on various articles of clothing, such as belts or vests, to direct a user through a space.^{37, 38} These are but the tip of the iceberg of all the experiments that have been done until now.

Even more have focused on low-vision environments in addition to the teams previously mentioned. Teams such as Ramirez, et al. have developed various concepts such as portable computing wedges for firefighter navigation³⁹ and an “augmented lifeline” rope with embedded sensors.⁴⁰ There are cloud-based indoor positioning platforms,⁴¹ breadcrumb sensor networks^{42, 43, 44, 45} and wireless sensor networks.⁴⁶ Others have looked at spatial orientation systems derived from inertial measurement units (IMU), mounted cameras, step sensors,⁴⁷ and even vibrotactile gloves for distance display.⁴⁸ Groups have also investigated low-cost solutions such as smartphones to help firefighters in low-vision situations.⁴⁹ Important contributions have been made in the realm of tactile navigation in low-vision environments regarding its performance in relationship to cognitive load. Elliot, et al,

demonstrated that tactile navigation may actually be preferable to a screen-based solution in situations intense visual stimuli.⁵⁰

Perhaps the proposal closest to this thesis that I encountered is “Personal Radar” by Riener and Hartl.⁵¹ Their solution, unlike the scores of belt- and vest-based tactile navigation systems already developed, is a fully self-contained system. They explore how a self-governed tactile system might lead a subject in dangerous environments, such as burning buildings, by assisting in obstacle detection and collision avoidance. This solution, however, still suffers from what afflicts the others as well: it is a fine technological display, but it is unlikely to ever be adopted by the public due to its unwieldy design and implementation. In fact, although several of the articles mentioned designing for the end user, the vast majority of experiments to this point have left much to be desired in the actual end user experience.

Perception in Navigation

To ensure a proper end user experience, I considered the fundamental concepts of visual perception to determine what might be transferred to the tactile senses. When we speak of perception, we must first begin with the property of shape. Shape is the most important aspect of perception because it provides more accurate information about objects than any other perceptual property, including depth, shading, and the orientation and edges of surfaces.⁵² Engineer and psychologist Zygmunt Pizlo defines shape as the “geometrical characteristics” of a tangible object that allow us to identify it veridically as unique from its environment.⁵³ These characteristics allow shape to be independent of the viewer’s position because “the shape of an object is intrinsic to the object,” and this cannot be said

for any other property.⁵⁴ The better information we have about objects in our environment, the better will be our interactions with them.⁵⁵ Perception’s ultimate goal is shape constancy, or the recognition of the same object from multiple angles.⁵⁶ This is achieved through an internal process called “figure-ground organization,” where the brain identifies the unique contours and regions of an object and mentally separates it from the background. According to Pizlo, shape is essential for this mental separation because it is the “only perceptual property that has sufficient complexity to allow an object to be identified.”⁵⁷ Of basic shapes, rectangle-based ones best allow for veridical percepts because of their complexity; they require at least four parameters to characterize their shape. Contrast this with ellipses and triangles which only require one or two parameters respectively to

characterize their shapes.⁵⁸ This suggests that any translation into a tactile device should maintain sufficient complexity for veridical perception.

This suggests that any translation into a tactile device should maintain sufficient complexity for veridical perception.

Shape complexity is an interesting concept in 3D perception because it is usually juxtaposed with the function of a simplicity principle, first introduced by Gestalt psychologists in the early twentieth century, and expanded upon over the past few years.⁵⁹ Basically, a simplicity principle says that the retinal image itself is not sufficient for the brain to interpret fully without implementing a priori constraints, or “schemata,” as Ulric Neisser called them,⁶⁰ to determine simpler shapes that make sense.⁶¹ This helps explain Neisser’s observation that human percepts are “usually accurate,” or that, in other words, we usually get it right when we see an object.⁶² But shapes need sufficient surfaces and volume in order for simplicity constraints to take effect and produce veridical percepts. Shape constraints are the key to reconstructing a 3D shape from a 2D retinal image.⁶³ What are these constraints—these mental functions—that work behind the scenes to translate a retinal image that is “upside-down, foreshortened, the wrong

size, exists in two slightly discrepant versions, and changes constantly as the eyes move?”⁶⁴

It has long been recognized that the human system successfully identifies objects in the world on a nearly perfect basis.⁶⁵ We see an object, such as a car, a leaf, a dog, and we thoughtlessly perceive it as (a) a 3D object, and (b) as separate from its environment. We can all do this. But how? The exact mechanisms we use, and the entirety of the system in which they fit are still a mystery. Yet there appear to be certain constraints applied nearly instantaneously within the visual system that reduce the number of possible objects the perceived 2D retinal shape could be. These constraints are simply human attempts to explain what our visual system inherently “knows’ or ‘assumes’ about the 3D objects ‘out there.’”⁶⁶ According to Pizlo, there are three main constraints the mind uses to reconstruct 3D shape from a 2D retinal image: (1) planarity of the object’s individual faces, (2) symmetry of the object, and (3) compactness of the overall size.⁶⁷ These constraints are manifestations of a priori simplicity principles at work. They are incorporated by the mind to help us more easily identify shape despite the loss of visual information due to our distance from the object or noise in the environment.⁶⁸

The first and probably most important constraint, is object planarity, or, the perception of joined corners of an object’s individual faces.⁶⁹ Regardless of how many faces are involved, if they share corners, the brain is able to invoke a planarity constraint to discern the shape from

the rest of the environment and transform the 2D retinal image into a 3D construct. Once the mind has created the 3D construct, it has achieved, as mentioned earlier, shape constancy. Only when the brain is able to recognize the shape from other angles are we able to process effectively and interact with the object.

In addition to planarity, symmetry constraints allow the brain to make sense out of an object that may be partially obscured. If the visible parts of the form appear to be symmetrical, the brain assumes the form of the rest of the object and mentally separates it from the background.⁷⁰ Obviously not every object in the world is symmetrical, especially objects such as rocks, trees, and wire structures. However, many, if not most of the items we encounter in the course of a day are close enough for the mind to overcome their asymmetrical differences, and reconstruct them in 3D, to enable shape constancy.⁷¹ Again, this constancy is the entire point of perception. It is the best way to understand objects so that we may interact with them.

A third shape constraint is that of compactness of the overall object size. It is usually used in conjunction with symmetry, and defined by Pizlo as “the volume squared, divided by the surface area, cubed.”⁷² In other words, the visual system assumes a perceived surface area that tapers as it gets further away. “The observer’s percept corresponds to a 3D shape that is slightly thinner in the depth direction compared to the maximally compact 3D shape.”⁷³ This allows a mental cutoff on the object to keep it small enough to perceive

and reconstruct.

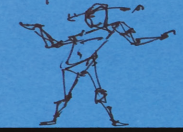
How does all of this relate to the task of low-vision navigation? It informs this proposal by introducing mechanisms to support interactions with 3D space in several ways. First of all, it lays a foundation for us to consider how figure-ground organization and shape constancy translate to touch. Although the tactile sense

Understanding of perception lays a foundation for us to consider how to translate sight to touch.

obviously strips away much of the visual identifier, can we substitute touch for the 2D retinal image, and rudimentarily translate that to a 3D mental construct to lead the user? Perhaps shape complexity could be introduced into the body through high resolution pulse swarm patterns as a retinal substitute. We can also get more specific with questions such as how might we eliminate shape ambiguity through touch? By extrapolating the observation of the four parameters contributing to rectangular complexity, touch mechanisms might also be conveyed through complimentary patterns that characterize the shape of an obstacle in front of us. Although a system like this may not be immediately useful, with a bit of practice, discerning these tactile patterns could become a valuable skill.

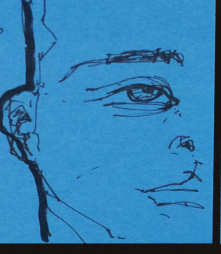


RUS OFTEN HAS A DIFFICULT TIME FINDING HIS WAY AROUND PLACES.



HE'S GOING TO PACIFIC PLACE FOR THE FIRST TIME (A COMPLEX INTERIOR SPACE)

HE IS WEARING A COMPUTER SCREEN DIRECTLY ON HIS EYES. IT IS EMBEDDED ON HIS CONTACT LENS



THE MALL HAS A SCANNED 3D FLOOR PLAN AVAILABLE

THIS 3D DATA IS AVAILABLE TO RUS' NAVIGATION SYSTEM.

LANDMARKS SUCH AS IND. STORES & RESTROOMS ARE TAGGED W/ NAME + LOCATION + GENRE, DATING, ETC.

FIGURE OUT HOW HE SELECTS LOCATION - INTERACTION, ETC.

PHASE ONE: STEP-BY-STEP

PATH TO DESTINATION ILLUMINATES

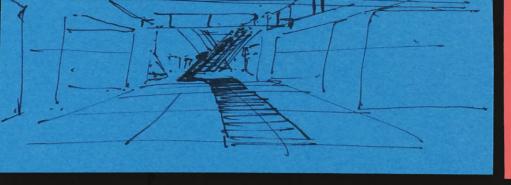


FIGURE OUT INTERFACE (SHOWING ALL FLOORS AT ONCE; PATH, ON SCREEN INFO, ETC.)

BROWSING FEATURE: DESTINATION IS UNSURE ("SHOW ME ALL SHOE STORES") (HIGHLIGHT EACH STORE ALONG PATH)

PLAN OUT EVERY GESTURE + WHEN HE WILL DO THEM SO

PHASE TWO PERCEPTION

NOW, LET'S COUPLE A VISUAL DISPLAY W/ PHYSICAL SENSES.



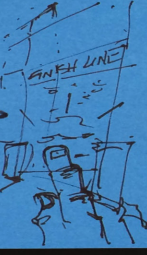
COULD SHOW THE DRIVE AROUND A MALL PARKING LOT - 3D DATA ACCESSED & ACTUATORS BEGINNING TO REALLY FIND STORE.

RUS' CLOTHING IS EMBEDDED W/ PULSE TECH. UNFLOWER.

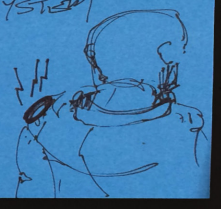
ACTUATORS FROM HEAD TO TOE ARE MAPPED TO THE MALL'S 3D SPATIAL DATA.



RUS CHOOSES A DESIRED LOCATION



IT'S ON THE 4TH FLOOR. THE SYSTEM REGISTERS & HIS LEFT SHOULDER BEGINS TO PULSE.



AS RUS MOVES THROUGH THE SPACE, THE PULSE REMAINS FIXED ON THE DESTINATION, SO THE PULSE SHIFTS FROM ONE SIDE OF HIS BODY TO THE OTHER

FIGURE OUT HOW TO MAP BOTH VERTICAL & LATERAL SPACE TO THE BODY

HOW DOES IT CHANGE DYNAMICALLY W/ OUR LOCATION?

FIGURE OUT HOW BODY MOVEMENT (ROTATION ON JOINTS, ETC.) CAN INFLUENCE FEELING COMPREHENSION

THE LAST TEN FEET HOW DOES PULSE/SYSTEM CHANGE AS TURN OR DESTINATION APPROACHES?

"WHERE IS MY CAR?" PULSE FEELING

I also began working through some initial scenarios to envision a future concept uninhibited by technological constraints.

CONTACT LENS HUD

MEET RUS HAWK

HAWK HAS A DIFFICULT TIME FINDING HIS WAY AROUND.

(HUD selection gestures)

LANDMARKS ARE TAGGED & AVAILABLE.

PACIFIC PLACE

HE'S FROM OUT OF TOWN

HE'S WEARING A CONTACT LENS...

THIS IS THE FIRST TIME HE'S BEEN TO PACIFIC PLACE (A COMPLEX INTERIOR SPACE).

PATH ILLUMINATES.

MORE HUD INTERACTION GESTURES

PHASE 2

THE MALL HAS A 3D FLOOR PLAN AVAILABLE.

now lets test more physical senses involved

Ind. fibers infuse w/ actuators throughout clothing.

Available to Hawk's Navigation System

embedded

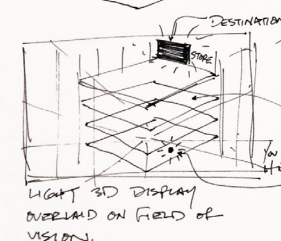
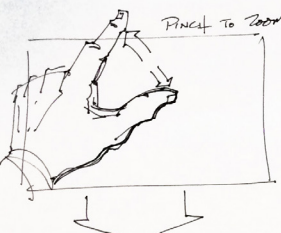
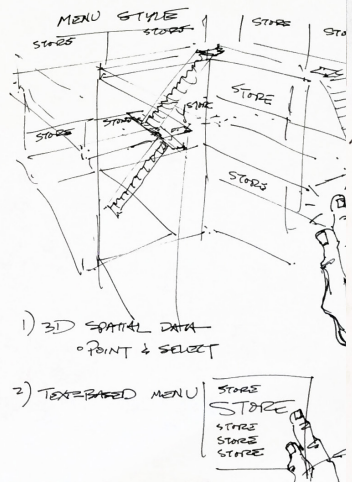
MAPPED TO CLOTHING

Research & Ideation: Sketching

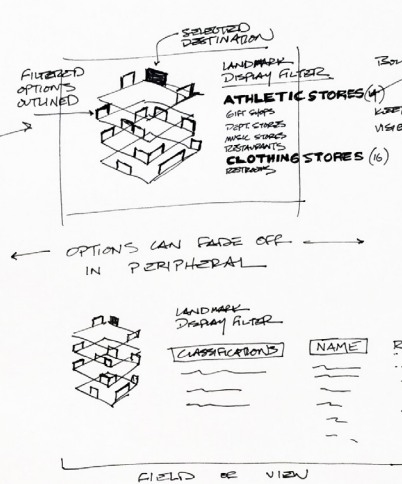
- 18 STORES + 2 RESTROOMS
- 15 STORES + 2 RESTROOMS + ELEVATORS
- 16 STORES + 8 RESTAURANTS + 4 RESTROOMS + ELEVATORS

SELECTION BY:

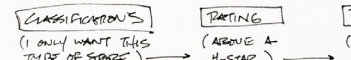
- 1) CLASSIFICATION
- 2) BROWSING
- 3) PROXIMITY
- 4) NAME
- 5) RATING (USUALLY IN COMBINATION w/ #1, 3)
- 6) SHOPPING LIST → SYSTEM COULD ORGANIZE PROGRESS THROUGH SPACE BASED ON LOCATION OF LIST ITEMS.
- 7) WANTED ITEM / ACTIVITY (WOULD PROMPT USER TO ENTER SPECIFIC REQUESTS).



How do we treat North/South orientation w/ the 3D map?



SHOULD LIST THESE IN AN ORDER THAT ALLOW WATERFALL FILTERING - I.E. EACH SELECT NARROWS AVAILABLE OPTIONS IN THE NEXT

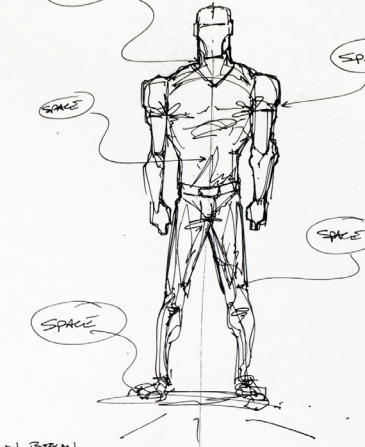
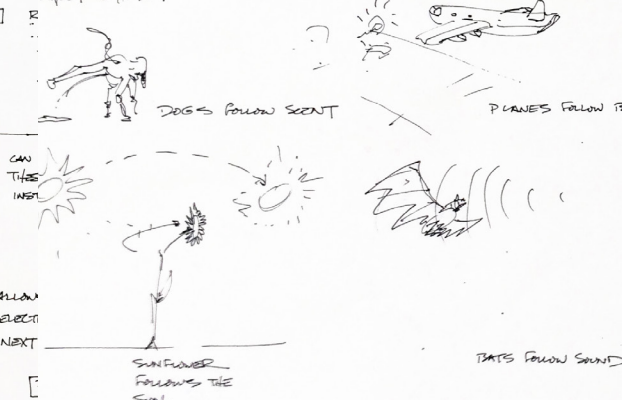


SPATIAL PERCEPTION

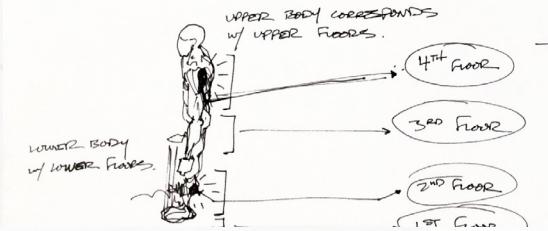
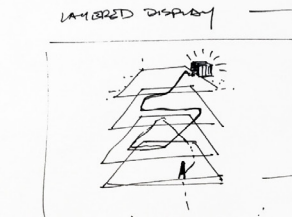
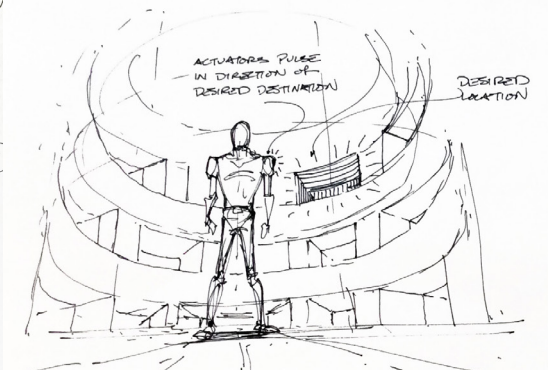
LET'S COMBINE A COMPREHENSION VISUAL SYSTEM WITH A USUAL DISPLAY (SCREEN).

USER CAN DERIVE INSIGHTS THAT COULD INFORM A FUTURE SCREENLESS SYSTEM OR THE BLIND.

WHAT FOLLOWS SOMETHING THAT EYES?

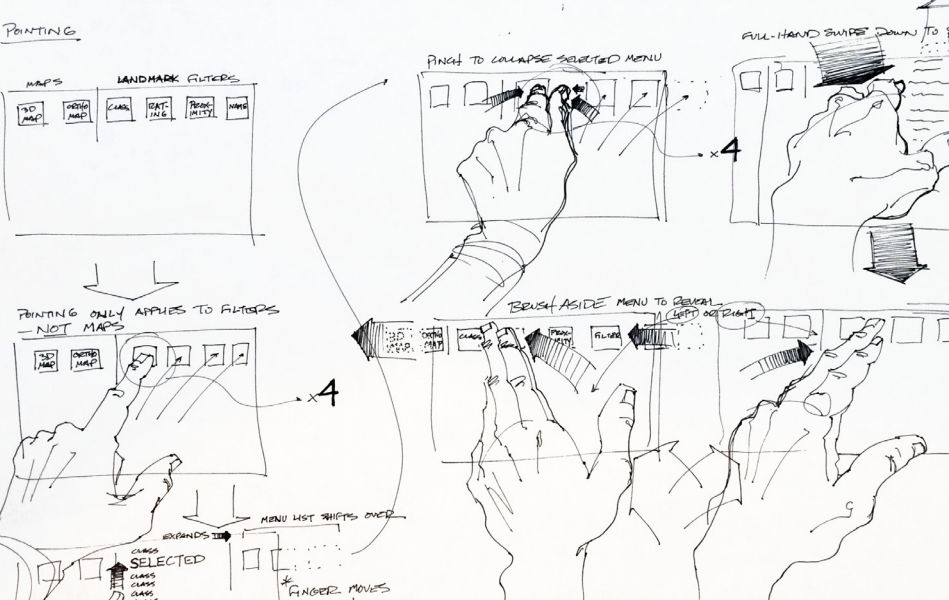


SPATIAL PERCEPTION



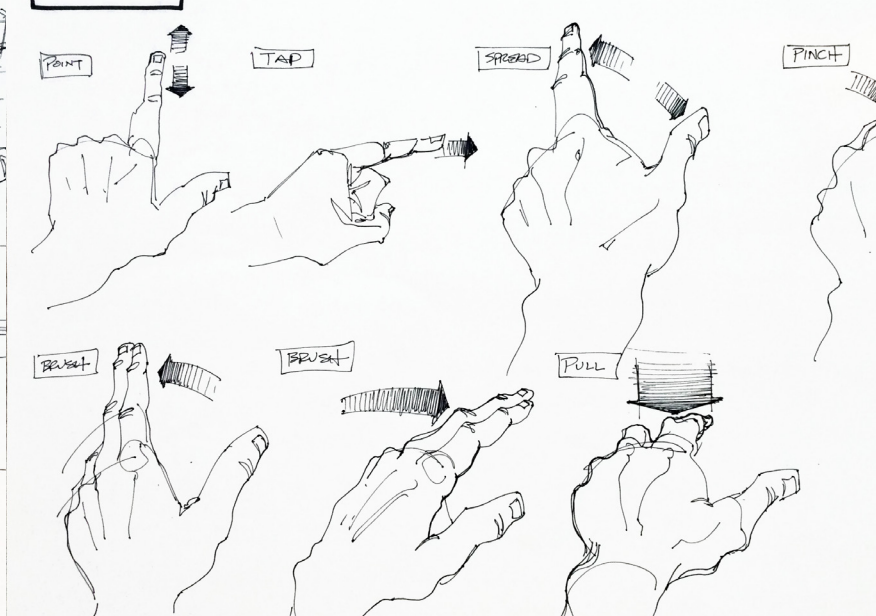
12.6.14 THESIS

GESTURES

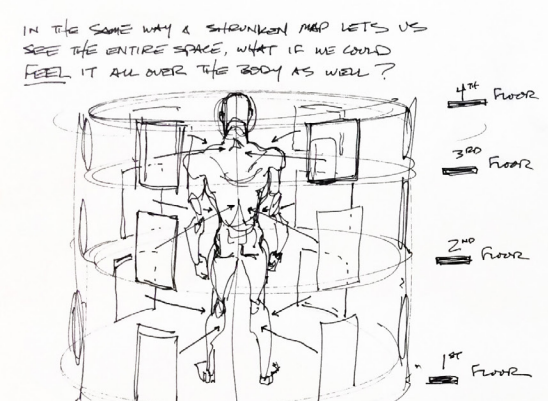


12.6.14 THESIS

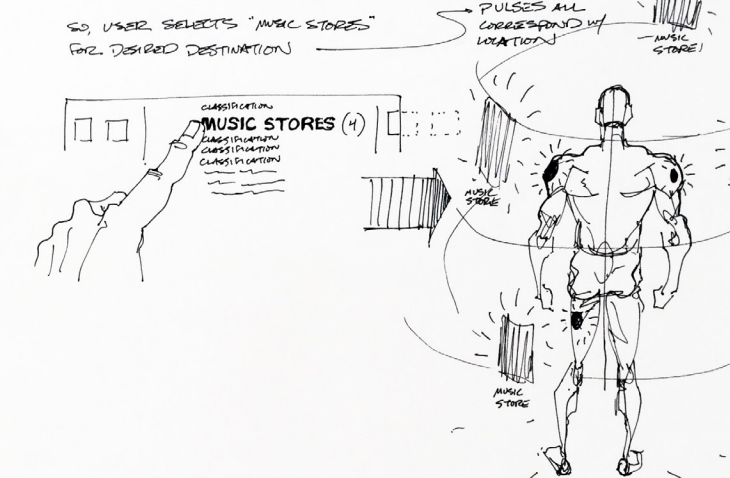
GESTURES



SPATIAL PERCEPTION

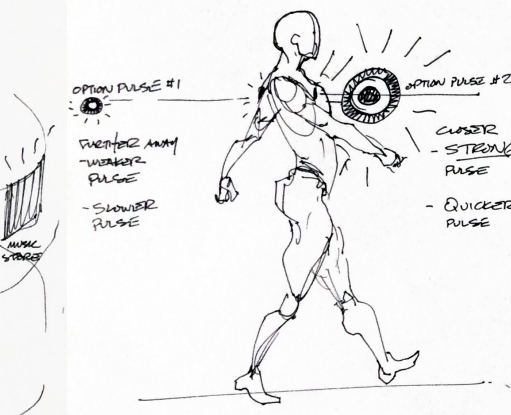


IN THE SAME WAY A SHRUNKEN MAP LETS US SEE THE ENTIRE SPACE, WHAT IF WE COULD FEEL IT ALL OVER THE BODY AS WELL?



QUESTION: HOW DOES THIS CHANGE AS USER GETS CLOSER OR FURTHER FROM EACH DESTINATION?

TACTILE DEPTH PERCEPTION



RATE OF INTERVAL PULSE = FORCE + SPEED

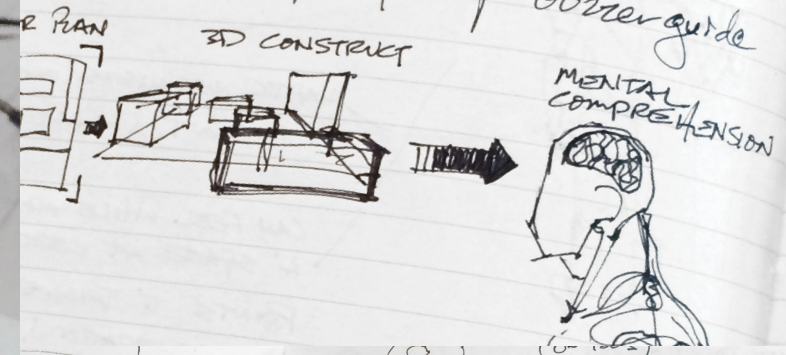
AFFECTED BY: USER DISTANCE FROM DESTINATION + MOVEMENT SPEED



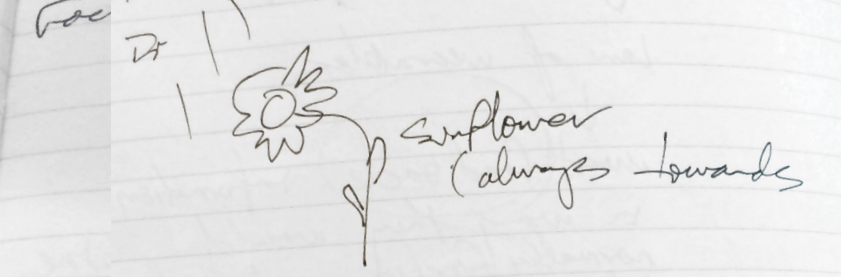
IF WE WANT TO INTERACT WITH THE ENVIRONMENT
 ITSELF, WOULD THAT HELP US DEVELOP
 CLEARER COGNITIVE MAP?

clearer as in understanding the space
 → where I am in relation to it?

NOT a step-by-step buzzer guide

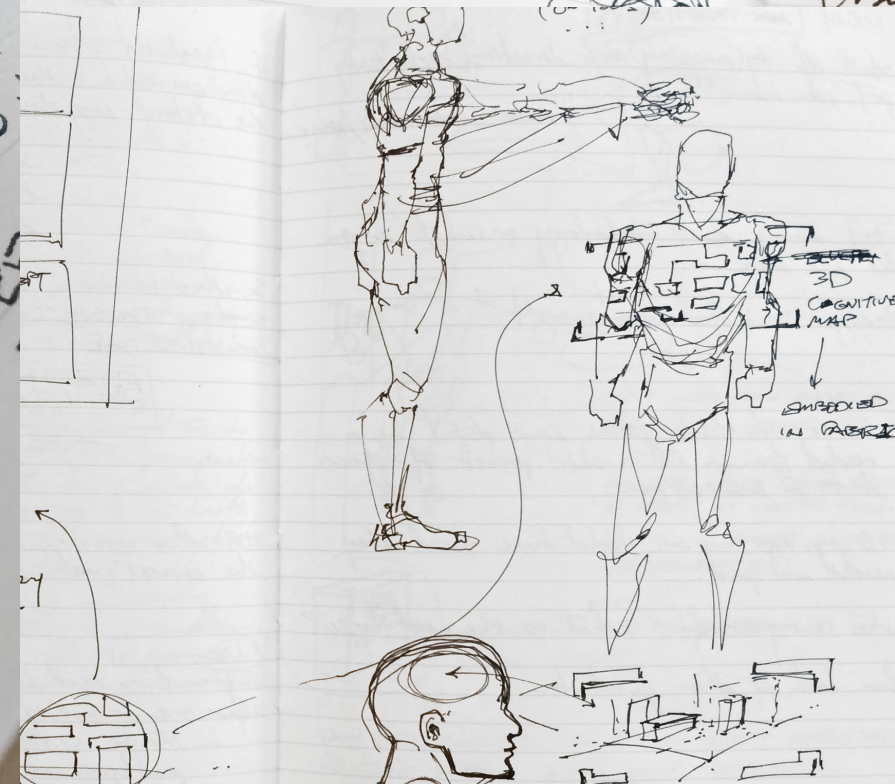


11.2
 perception of info in brain = wearable



show inspiration from nature
 Invisible thread → follow me around

* what c
 BIOMIMETIC
 DNA



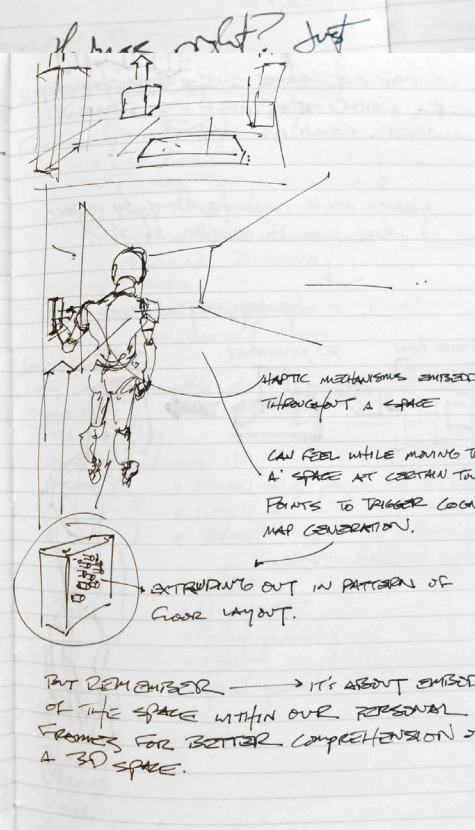
MAIN DIRECTION
 off by mapping each direction each body
 on mobile
 i.e. KNEE - FORWARD / BACK

worry about technology or what anyone
 as done.
 ie it + find your insight *

ex. The razor phone came about as a
 id item to fit in shirt pocket of dress
 for business men.
 20 yrs ago, no one would have said they
 had an iPad.

is my insight? what is the need I see?
 look at other products.

a car window buttons
 push or they pull a way



they do.
 come up
 original
 how long
 me: sh
 in indoo
 shu: /
 coming
 me: A
 shu:

While ideating through potential design responses, I found it helpful to consider the three diverse scenarios mentioned above in which a tactile navigation system might be useful. The first situation I considered is firefighters in burning buildings. It goes without saying that firefighting is a dangerous profession. In 2013, 106 firefighters died while on duty, and 55 of those died from activities at a fire scene. 29,760 were also injured while fighting fires.⁷⁴ These fatalities result from various accidents such as collapsing roofs, flashovers, etc., and often they stem from firefighters becoming disoriented and lost within a fire structure. They go into burning and smoke-filled buildings to determine danger levels, shut off electricity and gas, to fight fires, and, most importantly, to save lives. Burning buildings are obviously extremely dangerous. Fire weakens the overall structure so that floors, walls, and roofs can collapse without warning. There is a constant danger of explosions,

burns, flying glass and shrapnel, and, even in some situations, decapitation.⁷⁵ These extreme conditions are complicated by thick black smoke that reduces visibility down to zero percent in many cases. Because of the heat which causes the smoke to rise, firefighters must often crawl through a space completely blinded, feeling their way around. Under these conditions, they frequently become disoriented and lost, as attested by countless incident reports.

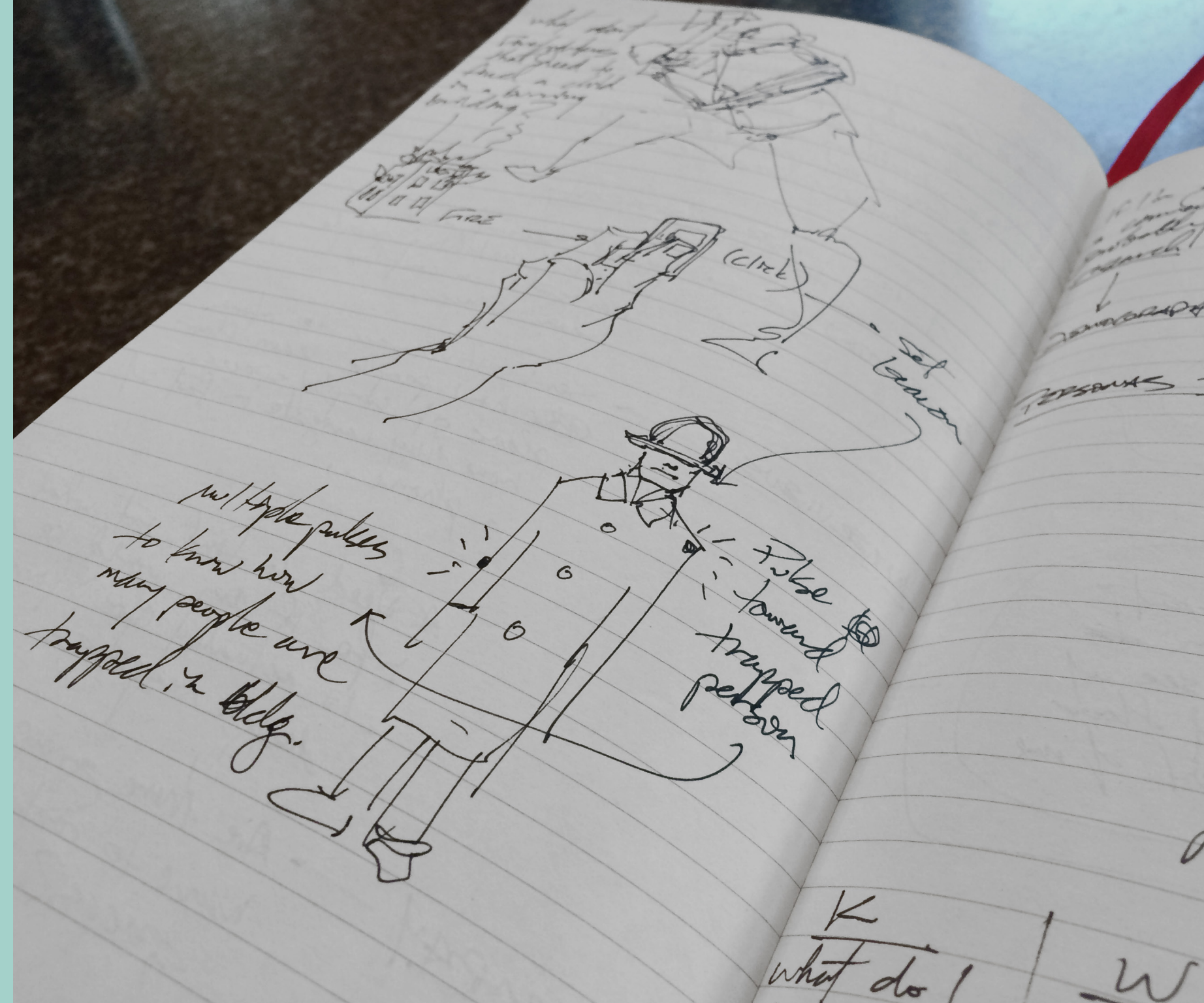
Oftentimes, firefighters will bring in a fire hose with them that can double as a tangible wayfinding device out of the building to prevent them from getting lost. But hoses are limited in at least four major ways:

1_ They can burn up in fires⁷⁶

2_ They may be too short⁷⁷

3_ They may be too heavy⁷⁸

4_ The safe path of the hose may become closed



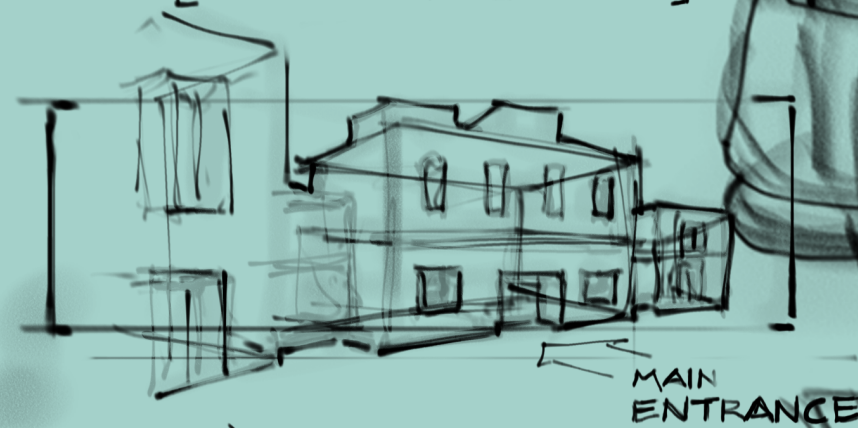
Reduced visibility and high stress severely hampers a firefighter's ability to navigate a space. When vision is impaired to prevent optical understanding of a space—such as when the air is clouded with smoke—we must find another way. How might we help firefighters navigate low-visibility and dangerous scenarios more effectively? Let us look at some technological issues and interventions we might be able to put into place to address such tragedies in the future.

First of all, according to Scholz, et al, the infrastructure cannot be used or relied upon for any solution because it is in the process of being destroyed by fire.²⁹ But this is the beauty of the Internet. If 3D spatial data were available for each building, the incident commander could download it to a tablet outside and triangulate positions inside. Perhaps he or she could know where the nearest exit is for firefighters inside, and guide them out accordingly.

Project this into the future, and we can easily see that if this scanned 3D floor plan data helps in emergency management and reducing costly structural damage, insurance companies might require all buildings to provide this scanned 3D data before it will get coverage. This could proliferate the availability of this data to 80-90% of all buildings.

In addition to the infrastructure being unusable for any potential design response, triangulation is another tricky issue that has caused every team to fail to this point. Phenomena such as location drift make it very difficult to locate a person indoors.

3D FLOOR PLAN [HOLSTON BLDG]



SECONDARY ENTRANCE

10,591 SQ. FT.
BUILT 1971
OWNED BY: ~~~~~
USED FOR: ~~~~~

INSTEAD



WiFi for INDOOR TRIANGULATION

BAD IDEA

INFRASTRUCTURE IS BEING DESTROYED

But what if the system could take the scanned 3D data of the space and roughly estimate the global coordinates of a destination such as the boiler room or the kids' bedroom? It could lock on to the destination inside the building, where the user is headed, or it could lock on to the escape route. In other words, global positioning could move indoors by virtue of the scanned 3D spatial data.

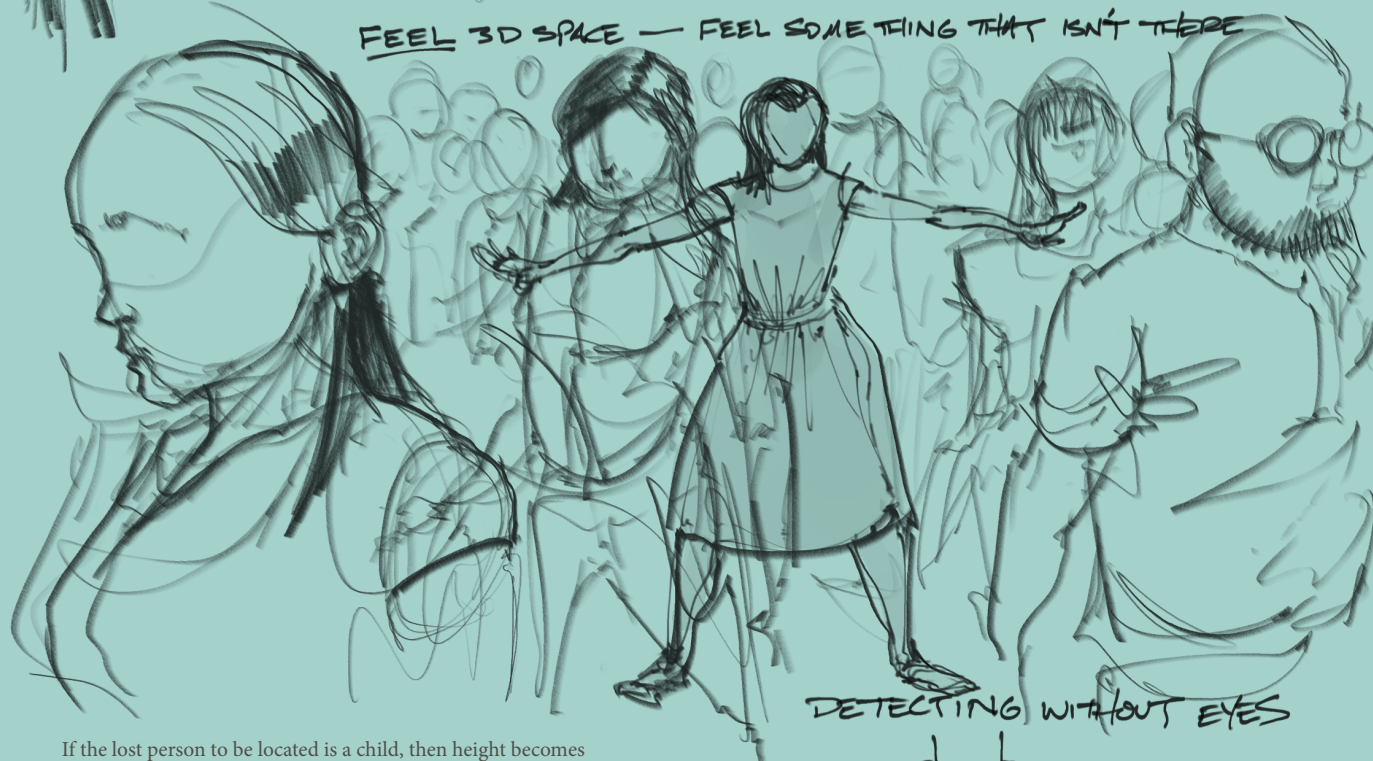
For example, imagine that we know a fire started in the boiler room. The scanned 3D data allows us to know where it is in relation to our position by the hydrant across the street. The system knows the hydrant is 52' from the Bravo exposure. Based on where we are in between, the system could estimate our position and be constantly recalculating escape routes based on real time positional and environmental changes.

ACCESS A SCANNED 3D FLOOR PLAN

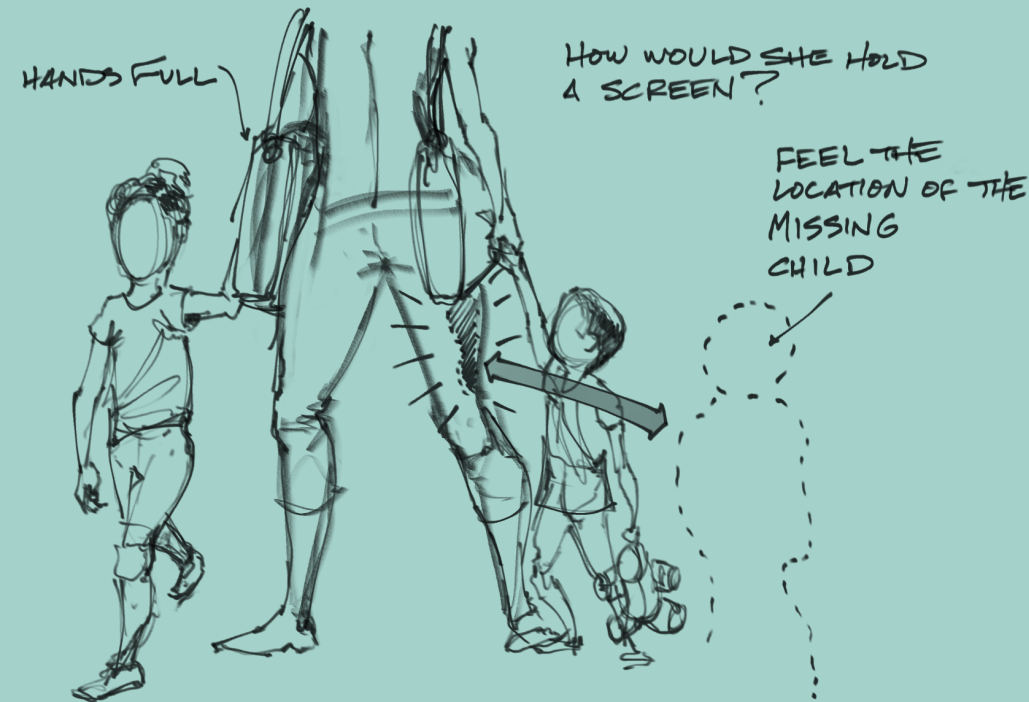
- o CALCULATE ENTRANCE & ESCAPE ROUTES ON THE FLY
- o GLOBAL COORDINATE TRIANGULATION?



This navigation concept could also be of great benefit to parents of small children in crowded places. For those who have ever been tasked with watching them know it would be ideal to have some sort of ability to track them hands-free for several reasons. First, a crowded place implies an abundance of external stimuli—much of which consists of people. Like the proverbial needle in a haystack, it can be difficult to discern visually a particular person out of a crowd—especially if that person has no significantly differentiating features. A bright red backpack or a purple hat may be white noise in a sea of brightly-colored accessories.



If the lost person to be located is a child, then height becomes a visually-limiting factor, as their head may not even be seen above a group of grown adults. With vision obscured, it becomes crucial to find another way to locate them.

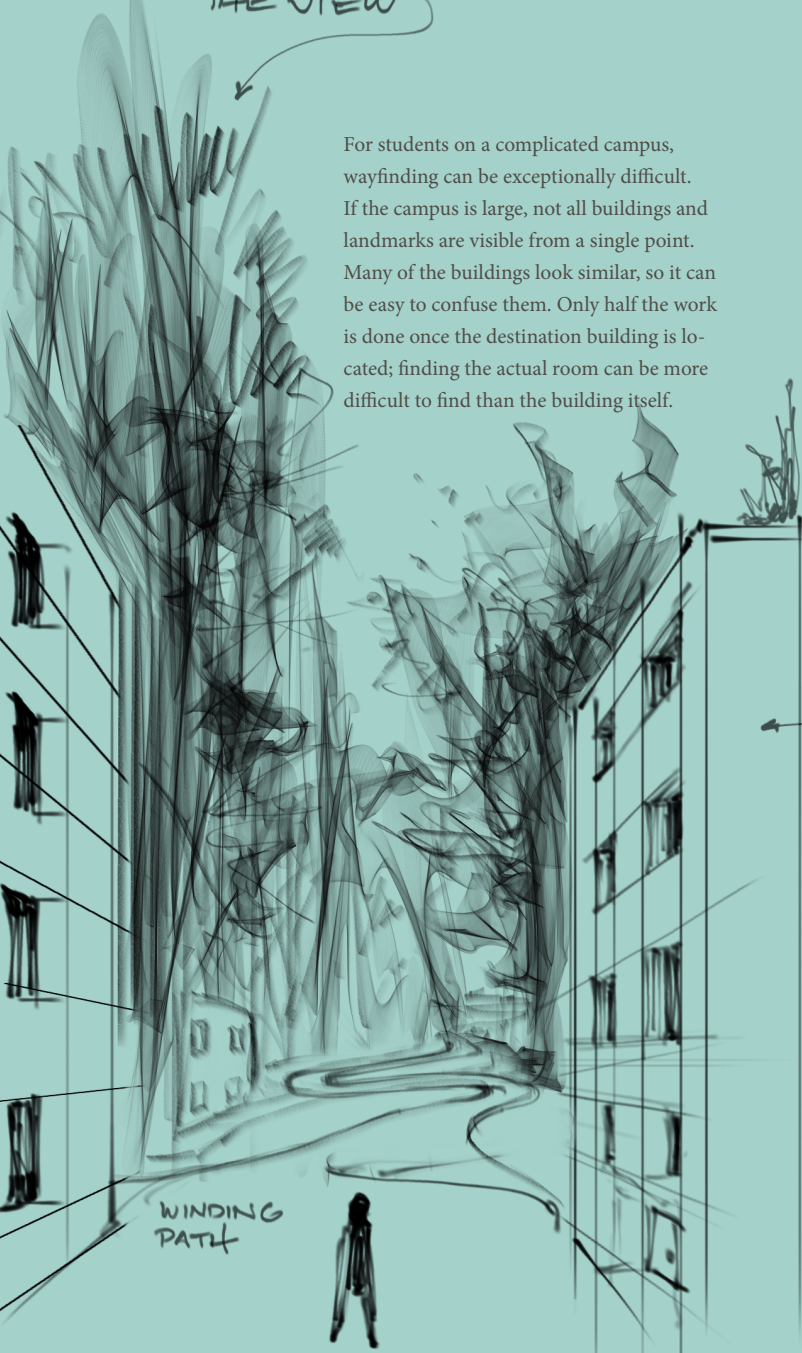


To complicate the situation, consider a mother has one lost child, and two remaining. Her hands are needed to hold the hands of her children, and perhaps other objects, while she frantically searches for the lost child. Thus the proposed design concept should remain hands-free in addition to eyes-free.

Addressing this through touch seems to be a logical route. Imagine a tactile system in which we can feel a distanced child through a pulse oriented toward their location. It might be reasonable to activate the pulse once the child has strayed a certain amount of feet away. Once a threshold of ten feet is reached, a faint pulse activates in the direction of the child. As the distance increases, the pulse correspondingly grows until it takes over an entire portion of the body. As the distance is narrowed, the pulse shrinks as the volume of voices in a game of Hot+Cold.

TREES OBSCURE THE VIEW

For students on a complicated campus, wayfinding can be exceptionally difficult. If the campus is large, not all buildings and landmarks are visible from a single point. Many of the buildings look similar, so it can be easy to confuse them. Only half the work is done once the destination building is located; finding the actual room can be more difficult to find than the building itself.



WINDING PATH

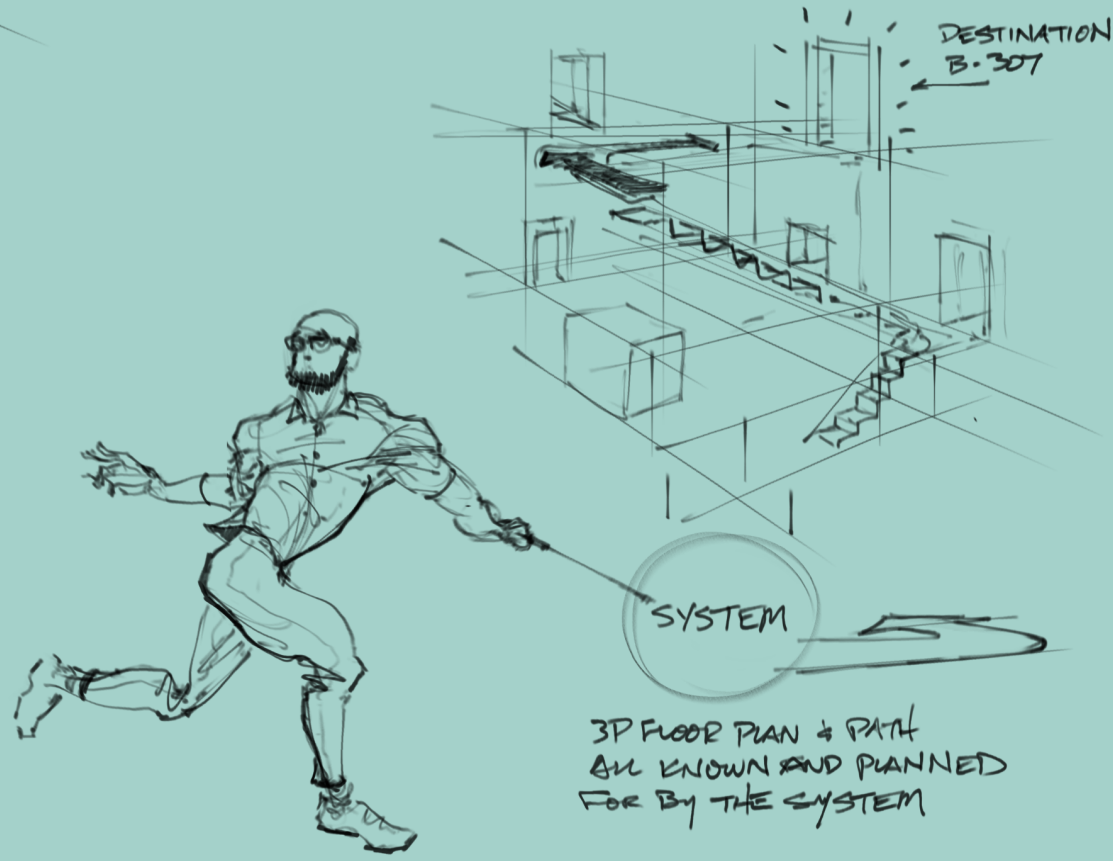


CAN'T SEE FULL PATH - OBSCURED

Once inside, a path to our destination is not entirely visible and rarely linear. If we cannot see the full path, and we have to turn and go up or down between floors around obstacles, we may be severely hampered from reaching our destination in a timely manner.

BUILDINGS ALL LOOK THE SAME

As previously postulated, a system that always orients to the destination may be helpful in low-vision environments. But how might we address the remaining issues of navigating around obstacles in our path and knowing which immediate direction will allow us to reach the final target? Imagine if a system could lead us by the nose to our destination—literally pull us in the direction we needed to go? What if it could take into account the non-linear pathway to the destination and lead us around the obstacles and to the elevators needed.



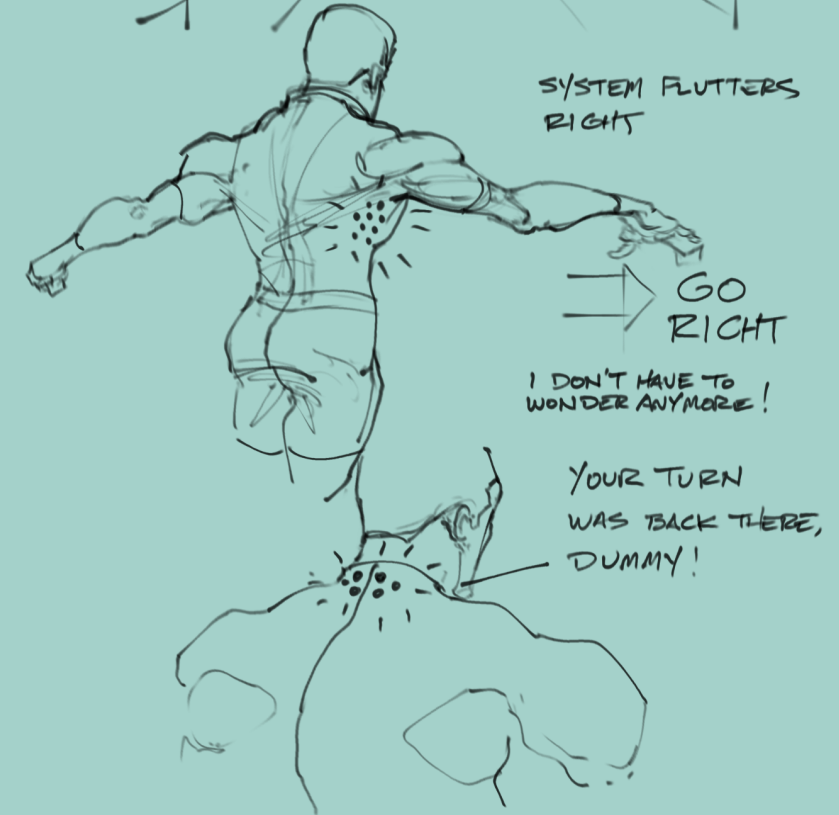
SYSTEM

3D FLOOR PLAN & PATH ALL KNOWN AND PLANNED FOR BY THE SYSTEM

Perhaps it is a system that simply nudges in the right direction at decision points through "break" patterns? A full-body swarm flutter left; a swarm pulse on the back of the neck suggesting we missed our turn, or other patterns could be the difference between seconds and minutes of getting lost and finding our way back. A system that takes 90% of the guesswork out of "forks in the road" while remaining hands- and eyes-free would be a successful one.



WHICH WAY TO GO?



SYSTEM FLUTTERS RIGHT

GO RIGHT

I DON'T HAVE TO WONDER ANYMORE!

YOUR TURN WAS BACK THERE, DUMMY!

The Challenge: Rat in the Maze

With this secondary information in hand, I wanted to understand navigation and wayfinding through my own research. I observed eight volunteer subjects navigate through a complex indoor space to discover what people do to find their way around, what might be done to help, and identify potential navigational needs and pitfalls. Four of these volunteer subjects self-identified as having a poor sense of direction, while the remaining four said they have a good sense of direction.



Participants were asked to find a specific faculty member's office within the Old Main at St. Martin's University in Lacey, WA, without knowing the office number or which floor on which it was located. Old Main, a 120,000-square-foot L-shaped monster, is the largest building on campus, and is quite difficult to navigate.



The entry way makes the space feel deceptively small by immediately heading into a horizontal wall that blocks access to the rest of the building. Right off the bat, the user must decide to go right or left, without any sense of how large the structure actually is.



With four floors, most of the hallways look identical with very few distinguishable landmarks. Views of the outside are rare, causing frequent disorientation. Additionally, there are no faculty directories or floor maps located anywhere, so participants must work blindly. The purpose of this exercise was to observe two things:

1_ indoor wayfinding in an unfamiliar building

2_ people at confusing decision points



Subject: Don, 50

Directional Skill: Good

Strategy: Full lateral survey before proceeding vertically. Tries to base indoor orientation on external landmarks. When learning a space, only pays attention to where he is going. Ignores everything else around, including the rest of the floor plan. If destination changes, then has to start all over.



Subject: Loretta, 71

Directional Skill: Excellent with always knowing north, south, east, west

Strategy: Full lateral survey before proceeding vertically.



Subject: Jodi, 48

Directional Skill: Moderate

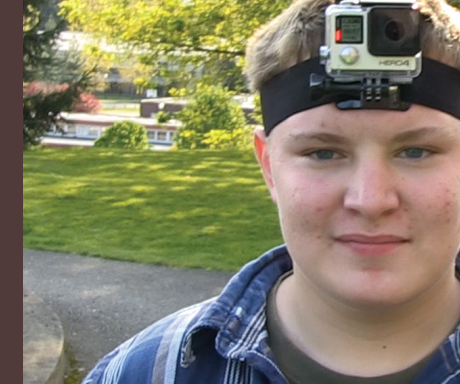
Strategy: Choose paths with most apparent options, no matter the length.



Subject: Shannon, 36

Directional Skill: Good

Strategy: Look for where office groups would be located (destination was an office).



Subject: Jacob, 16

Directional Skill: Moderate

Strategy: Portional survey and hope to stumble upon destination during process. Work on small part of left side first, then next floor, small part of left side, then next floor, etc. This allows him to get one side of building done so he never has to come back.



Subject: Marissa, 18

Directional Skill: Poor

Strategy: Survey floor-by-floor hoping to stumble upon destination



Subject: Juli, 45

Directional Skill: Poor

Strategy: Quick survey of the layout before deciding on plan of attack. Decided to attack half of the building vertically, then go to the other half vertically.

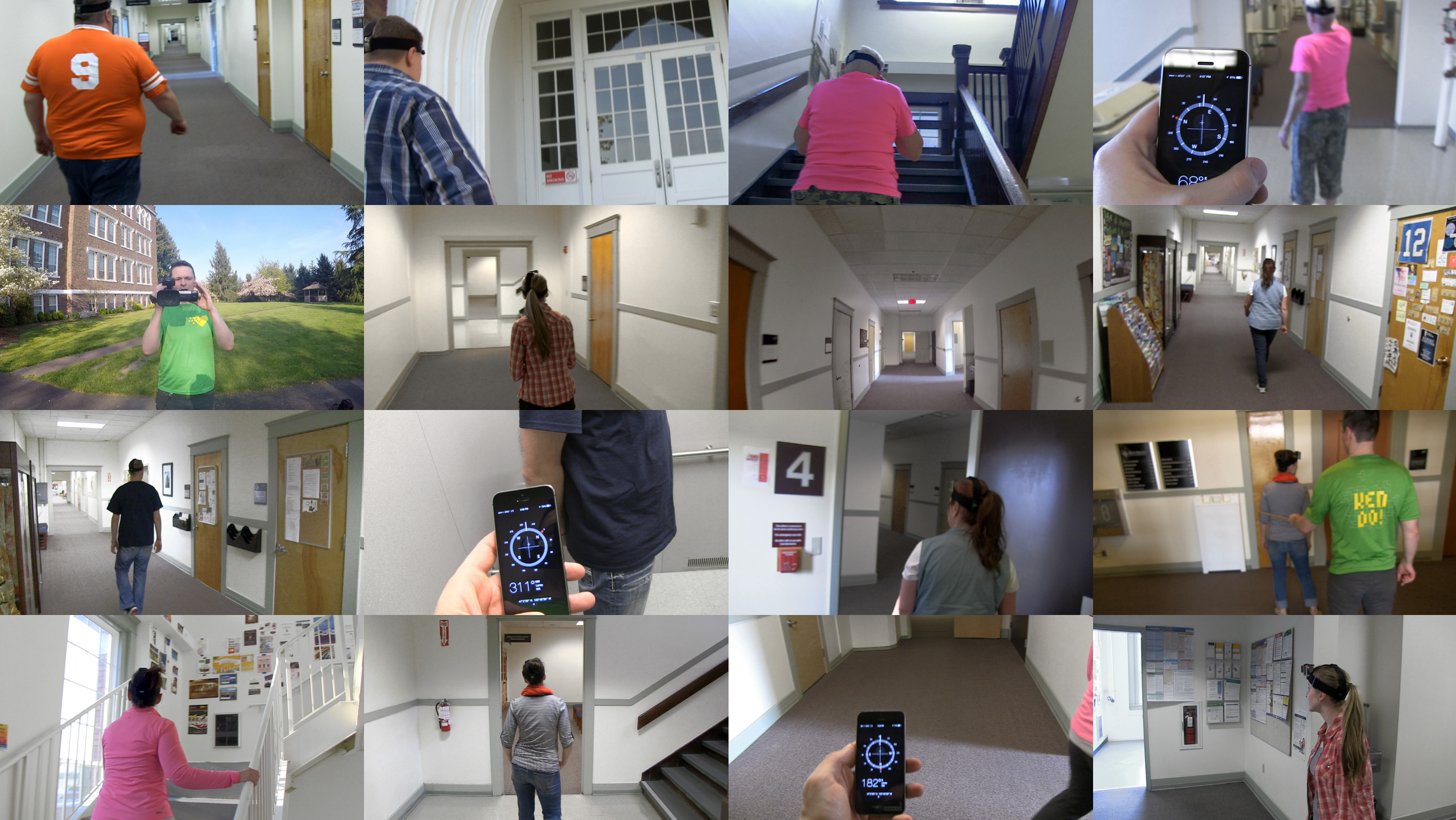


Subject: John, 47

Directional Skill: Good

Strategy: Full lateral survey before proceeding vertically. Kept track of orientation throughout the turns, but needed external landmarks through window to be sure.





The test here was not so much whether they could find the office. With enough trial and error, each would eventually find it. The real question was how they would find their way back out. Would they be able to stay oriented toward the entrance, and would such a thing even be helpful?

Each participant filmed their own walkthrough with a head-mounted GoPro camera, while I walked with them filming a second angle. I allowed them to fail several times before nudging them to the fourth floor with subtle hints. It quickly became apparent that without hints, each participant would be looking for several hours.

The maze-like properties of the building and lack of landmarks were a great equalizer between those who self-identified as directionally good or poor. Average tour time was 7.1 minutes, and everyone became at least slightly disoriented at some point.

Observations & Insights

Observation #1

Dearth of landmarks lead to disorientation

As participants worked their way out they tried to orient themselves toward the entrance and proceed accordingly. Each participant became disoriented at least once without knowing it. I queried them what direction they were heading and at times, they thought they were going in a different direction than what my iPhone compass showed. This, in turn, affected the choices they made to get back out of the building.

Disorientation can happen to anyone whether they are good at directions or not. Directional assistance would therefore be of great help to anyone in landmark-deficient, or low-vision situations.

Observation #2

Improper cognitive map leads to confusion

Clear views of our current space help comprehension. A scaled representation of the space oriented to the layout of our current location, as on a map, allows us to more quickly comprehend the layout. Without a clear understanding of properties of the space, such as size, shape, and number of floors, it becomes easy to make wrong navigational choices based on incorrect assumptions, which, in turn, can adversely affect wayfinding.

It is difficult to gain this understanding from a first-person view inside the structure. When we first enter a building, much of the floor plan is obscured by ceilings, walls, and other obstructions. At the initial point of building entry, the floor plan appears as a big jumbled mess to an unfamiliar visitor. But from a birds-eye view, the floor plan makes much more sense. If we can get such a view and look down, we may be able to gain more of an understanding. However, most complex buildings do not allow such a vantage point. The challenge is in finding a way to transfer the floor plan into a meaningful mental construct when we are in the weeds.

For example, Don, a “directionally good” candidate, commented on his initial walkthrough that it was “not a very thick building.” Because the building appeared to be a simple linear building from the outside facade [photo here], and the entrance led to a perpendicular hallway only flowing right or left [photo here], he had the incorrect sense of a thin building with no hint of additional hallways. This led Don to form an incorrect cognitive map of the space that caused him to underestimate the overall volume. He wandered back and forth, thinking he could easily cover all of the floor. Once he discovered additional hallways, he realized it would be a much larger task.

Juli similarly did not realize there was more to the building to be explored. She thought she had seen it all, until a hallway revealed over half of the building she had not known was there.

Marissa, a “directionally poor” candidate, said she remembered the way out because she “only turned once” on her way in. This was not accurate, however, and she got lost when she got to

the second floor. The doors looked similar and she eventually realized they were not correct.

As we wander through a space in search of a destination, we quickly learn that a path is rarely a straight line, especially when multiple floors are involved. We must weave around, sometimes facing the destination and sometimes turning our back on it. The destination remains constant but the user does not. [Show Illustrator diagram winding path overlaid on photo of the building]

This environmental complexity guarantees a number of decision points that greatly slow wayfinding and increase confusion, no matter how good we may be at directions. John, for example, a “directionally good” participant, headed around the back of the building on a weaving path he understood to be the only way out. That path took twice as long as routes other participants took. Had he understood the actual space and his orientation to the entrance, or was even just nudged at decision points, his disorientation would have been limited and time to find the entrance reduced.

Observation #3

In public environments there is an abundance of stimuli

There is often much external stimuli that requires the user’s attention—obstacles and people to avoid, the path to the selected destination, etc. It is imperative that the navigation solution assist in ways that do not distract from the task at hand.

The Challenge: Pulse Tools

After observing physical indoor navigation, I needed to test my hypothesis that a full-body pulse system might enhance wayfinding. But it was still unclear what types of tactile stimulation would be useful. To determine what kind of information people can discern through tactile sensation, I developed tests using seven wooden dowels with tips of various widths. The three main objectives of this test were to determine the following:

1_ Discernibility of tactile stimuli

2_ Tactile response during cognitive load

3_ Max number of possible simultaneous pulses

To achieve this, I decided to use multiple simultaneous prods on various spots on the body with different sized tips to see if they could tell which was larger. I tested eleven participants' tactile sensory abilities under two different situations. The first type required the participant to simply stand and identify the pulse, while the second asked them to play a video game (Mario Kart) while being prodded.

Dowel Tip Measurements

0.3125 in



0.5 in



0.625 in



0.625 in



1.25 in



1 x 3.75 in



4.5 x 4.5 in





Subject: Shannon, 36

1.25" felt the same as the 0.3125" (Wrong)

3.75" block felt same as 0.625" round (Wrong)

4.5" block felt like "more of an area" than 5/8" round (Correct)

4.5" on lower left back, 0.625" on upper right back, 4.5" felt "way bigger" (Correct)

0.3125" on lower left back felt same as 0.625" on upper back (Wrong)

0.625" round and 0.625" square felt the same (Wrong)



Subject: Don, 50

Felt a small difference between the 0.625" and the 0.5" But when swapped sides, he said they felt the same. (Correct, then wrong)

3.75" and 0.625" - was not sure at first, but asked for them to be pressed harder, and then could tell 3.75" block was bigger. Only felt "a little" bigger, however. (Correct)

4.5" and 3.75" - said they felt the same. Applied on both upper and mid back with no difference. After looking at the tools after the experiment was done, he said he thought the square we were pressing him with was the 0.625" square, not the 4.5" block. It felt that small to him. (Wrong)

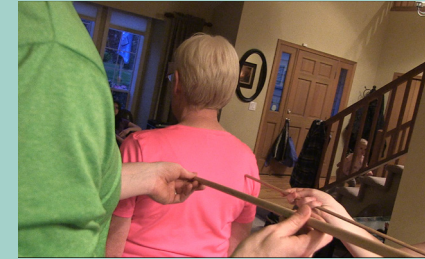
0.625" square and 0.5" round on arms - still could feel no difference. (Wrong)



Subject: Juli, 45

0.625" and 0.3125" - upper back, felt the same. (Wrong)

4.5" and 0.625" round - 4.5" felt bigger because she "could feel it on more space on her back." But when she saw the difference, she said they did not feel nearly that different. (Correct)



Subject: Loretta, 71

0.625" and 0.3125" - upper back, felt the same. (Wrong)

3.75" block and 0.3125" - upper back, 3.75" block felt slightly bigger. (Correct)



Subject: Jodi, 48

0.625" and 0.5" - 0.625" felt slightly bigger. (Correct)

Same 0.625" and 0.5" - this time she switched and said the 0.5" felt bigger. (Wrong) Was this due to pressure? Was it due to the hit angle?

0.5" and 4.5" - 4.5" block felt like it was "hitting more area." (Correct)

(Removed overshirt)

3.75" block and 4.5" block - 4.5" block felt bigger. She "could not tell what size they were, just that the 4.5" was bigger." (Correct)

0.625" round and 0.5" round - 0.625" round felt bigger. (Correct)



Subject: Bri, 16

0.3125" and 0.625" - Felt the 0.625" round was bigger. (Correct)

Same 0.3125" and 0.625" - this time she switched it and said the 0.625" round felt smaller. (Wrong)

3.75" block and 0.3125" - 3.75" block felt bigger. (Correct)





Subject: Marissa, 18

0.625" and 4.5" - 4.5" block felt bigger. (Correct)

3.75" block and 0.3125" - 3.75" block felt bigger. (Correct)

0.625" and 0.5" round - 0.625" round felt bigger. (Correct)



Subject: Justin, 15

3.75" and 4.5" - 4.5" felt bigger. (Correct)

Switched sides - 4.5" and 3.75" - 4.5" felt bigger. (Correct)

0.625" round and 0.5" round - felt the same. (Wrong)

0.3125" and 0.625" - 0.625" felt bigger (Correct)



Subject: Aidan, 13

0.3125" and 0.625" - 0.625" felt bigger "by a little bit." (Correct)

Repeated 0.3125" and 0.625" - pressed harder with 0.3125 and she thought it was bigger. (Correct)

0.5" and 0.625" - felt the 0.5" was bigger. (Wrong)

3.75" and 4.5" - felt the same (Wrong)



Subject: Caia, 11

4.5" and 3.75" - 4.5" felt bigger (Correct)

Kept it the same 4.5" and 3.75" - 4.5" still felt bigger (Correct)

0.5" and 5/8" - 0.5" felt bigger (Wrong)

0.3125" and 3.75" - 3.75" felt bigger (Correct)

Results

There were 38 total tests. 24 were correct for 63%

63% Correct

Pulse Test Pt. II: Cognitive Load

For this test, we moved the pulses around on the subjects' backs while they played a video game. One pulse was the broad side of the stick, and the others were the tips. We asked them to identify which one was the biggest while under a cognitive load from video games. Mario Kart was chosen because of the navigational aspect of the game.





Subject: John, 47

Game Amateur

- 2 pulses - one on his shoulder (Correct)
- 2 pulses - lower right side (Correct)
- 2 pulses, both tips, no broad side - said smaller one felt bigger (Wrong)



Subject: Juli, 45

Game Beginner

- 2 pulses - one on top right shoulder (Correct)
- 2 pulses - felt the same (Wrong)
- 2 pulses - felt the same, but the broad one felt "a little less pokey" (Wrong)
- 2 pulses, both tips, no broad side - felt the same (Wrong)



Subject: Don, 50

Game Amateur

- 3 pulses - top left shoulder (Wrong)
- 3 pulses, all tips, no broad side - all felt the same (Wrong)
- 3 pulses - all felt the same (Wrong)



Subject: Loretta, 71

Game Beginner

- 3 pulses - bottom left back (Wrong)
- 3 pulses - right middle (Correct)



Subject: Jacob, 16

Game Expert

- 2 pulses - one on his shoulder (Correct)
- 2 pulses - one on his shoulder (Correct)



Subject: Justin, 15

Game Expert

- 2 pulses - one on his shoulder (Correct)
- 2 pulses - one on his lower back (Correct)
- 2 pulses - lower right side was wider (Correct)



Subject: Marissa, 18

Game Expert

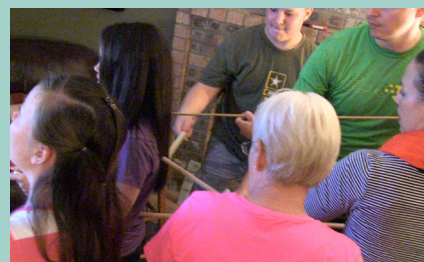
- 3 pulses - bottom right (Wrong)
- 3 pulses - "bottom left is going across my whole back" (Correct)
- 3 pulses - most pressure was bottom right (Correct) and longest seems to be top left (correct)



Subject: Jodi, 48

Game Beginner

- 3 pulses - right shoulder (correct, after much deliberate concentration)
- 3 pulses - below right shoulder (wrong)
- 3 pulses - bottom left (wrong)



Subject: Bri, 16

Game Expert

- 4 pulses - top right shoulder (correct)
- 4 pulses - the one in the middle (correct)
- 4 pulses - left shoulder (correct)



Subject: Caia, 11

Game Amateur

- 3 pulses - top right shoulder (Correct)
- 3 pulses, all tips, no broad side - bottom right (Correct)
- 3 pulses - bottom left back (correct)

Results

There were 29 total tests with additional cognitive load 18 were correct for 62%.
There were 67 tests total with 42 correct for 63%.

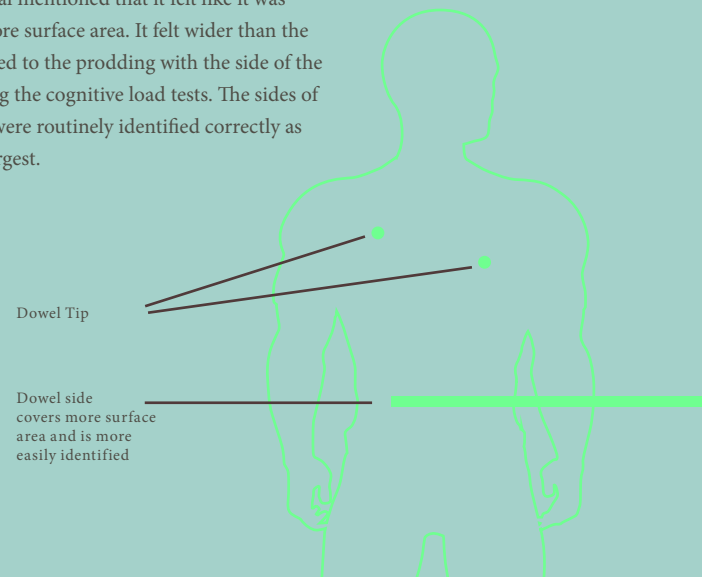
62% Correct

Observations & Insights

It was more difficult than expected to tell the difference between tip sizes and shapes. Participants often named the smaller size as the larger one, which probably suggests they were guessing because they felt too close to determine.

Participants could not discern between a circular and a square tip.

The most correctly identified tip was the 4.5" block. When asked how participants knew it was larger, several mentioned that it felt like it was covering more surface area. It felt wider than the other. This led to the prodding with the side of the dowel during the cognitive load tests. The sides of the dowels were routinely identified correctly as being the largest.



Participants were able to identify differences in pulse size, force, and location up to three simultaneous pulses.

Participants were able to easily discern between heavy and light pulse force.

Participants were also able to easily tell pulse location, even under heavier cognitive loads.

Cognitive load affected the participant's speed of the pulse identification. Those that were more familiar with the video game were able to answer more quickly.

Cognitive load also affected pulse identification accuracy. Experts of the game got 10 of 11 correct during game play (91%) while amateurs got 8 out of 18 correct (44%). One outlier in the amateur group, Caia, age 11, got all three of hers correct, thus slightly skewing the overall numbers. This suggests that as a person becomes more familiar with an activity at hand, the system may become more useful.

Cognitive Load affected pulse identification accuracy. Amateurs got 8 out of 18 correct for

44%

However, this study suggests that this can be overcome. Game experts got 10 of 11 correct for

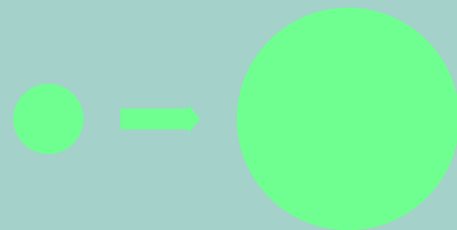
91%

How Does This Inform the Design?

#01

Pulse changes cannot be incremental

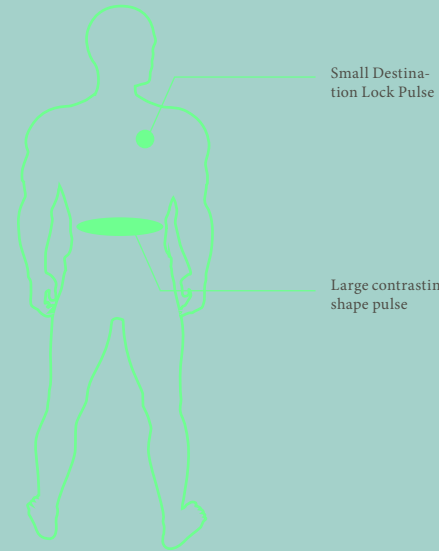
This research informs the design in several ways. First, it shows that the pulse needs to cover much more surface area than previously imagined. Pulse changes cannot be incremental. They need to be significant in order to be reliably discerned. They will also need to be augmented by force and location.



#02

It is possible to have more than one pulse at a time

The Sunflower system proposes to both lock on to the destination while leading along a path. This presupposes at least two separate pulses working simultaneously for much of a navigational exercise. The information gathered through this research shows that this should be discernible and useful by the user, and it prescribes the properties of the pulses themselves. They need to be very distinct from each other in surface area covered, pulse force, and pulse interval. If this is successfully achieved, then the user should be able to tell which pulse is which, even under increased cognitive load.

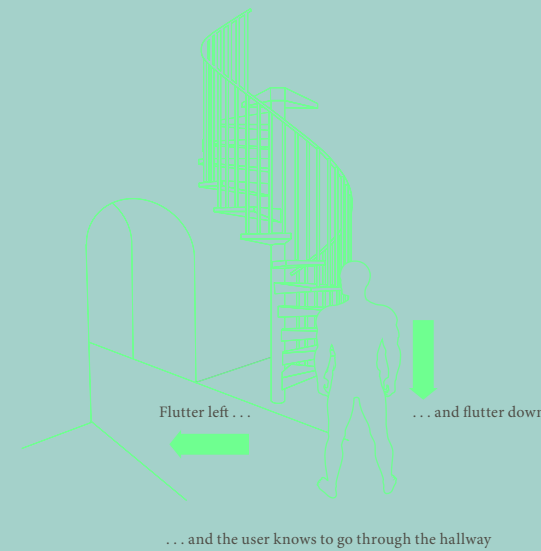


#03

Decision point nudging

Decision points increased the time needed to locate a destination by requiring participants to slow down and figure out which way to go. Once they did make a decision, some were wondering if they took the right path, rather than focusing on the current path at hand. Nudges with clear meanings at decision points should greatly increase the speed and accuracy of wayfinding activities.

A nudging pulse can easily tell the user to go left or right. But a major advantage of the Sunflower system is its ability to give clear feedback through combinations of both lateral and vertical body surface. The body is a vertical structure. The legs build upon the feet, the pelvis and torso build upon the legs,



and so forth. Just as a building is subdivided vertically between floors, so we can vertically segment the body frame accordingly. For example, imagine a decision point with two choices on the left. One choice goes up a flight of stairs, and the other down a hallway underneath the stairwell. A full-body system can distinguish by both a flutter left towards the direction, and up from the feet to the shoulders identifying the vertical stairs option as the correct one. Or, to signify the lower option, the flutter can reverse from the head down to the feet.

Additionally, because of the full-body coverage, the system can identify varying degrees of left or right. If there are two left turn choices underneath the aforementioned stairwell, the system can pulse in the exact direction of the turn, and can remain oriented as the user turns in that direction. Based on the user's selection, the system can give a reinforcing sternum lock pulse to give confidence, or a clear negative buzz to discourage the selection.

#04

Destination lock should help reduce disorientation

Often, when participants became disoriented, it was because they only missed one or two turns in the construction of their mental path as they traveled. A constant destination lock should give them a solid reference point to measure against their mental path.

#05

Volume pulse for cognitive map development

Due to the difficulty of telling how large a structure may be from typical vantage points, the Sunflower system gives a volume pulse upon first entering a building to suggest the size and layout of the space. For example, in an "L"-shaped building, such as in the research exercise above, the pulse would drag along the mid section from the user's point within the building and pulse outwardly in both right and left directions. After pulsing out the length of the hallway on the left side, it would then work vertically down to identify the remaining wing.

PART

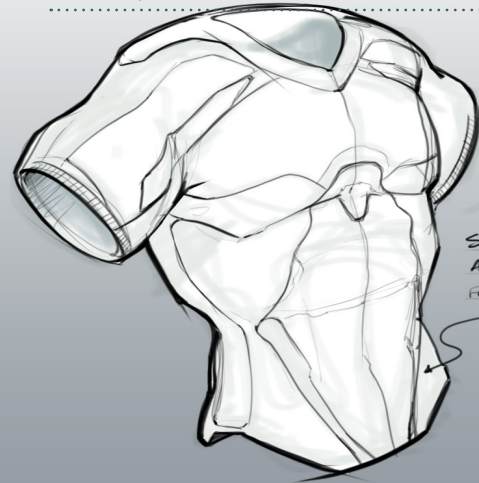
03

CONCEPT VISION

72



Concept ~~Visual~~ Initial Sketches



SIDE PANELS w/
AUGMENTED SENSORS
FOR PULSE COMPLEXITY



SIDE



BACK

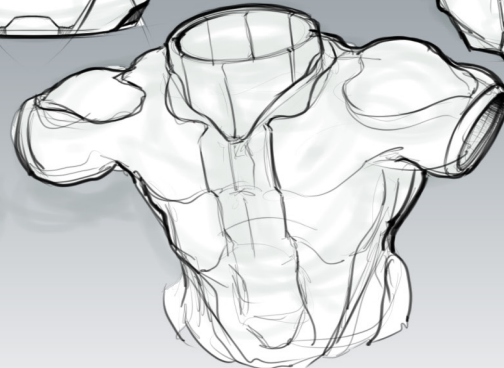
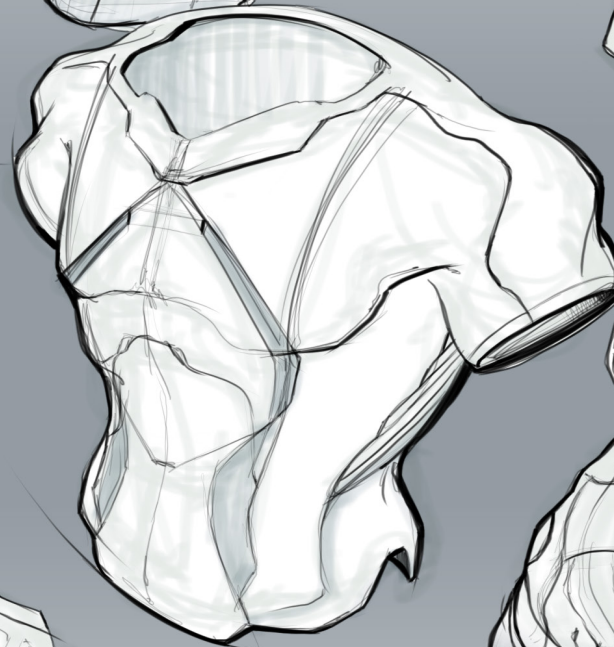


NODE FRAME AROUND NECK
BASE BEFORE NECK CAN SWIVEL



SUNFLOWER SUIT IDEATION
MASTERS THESIS : MAY 2015

DIRECTIONAL CHANNELS
WT RIGHT ACROSS TORSO



HUGS CONTOURS TO
ENSURE FULL NODE CONTACT




DAN
MOECK
2015

Initial design sketches exploring forms to incorporate research findings.




DIRECTIONAL
PANELS AVOID
PELVIS & KNEES

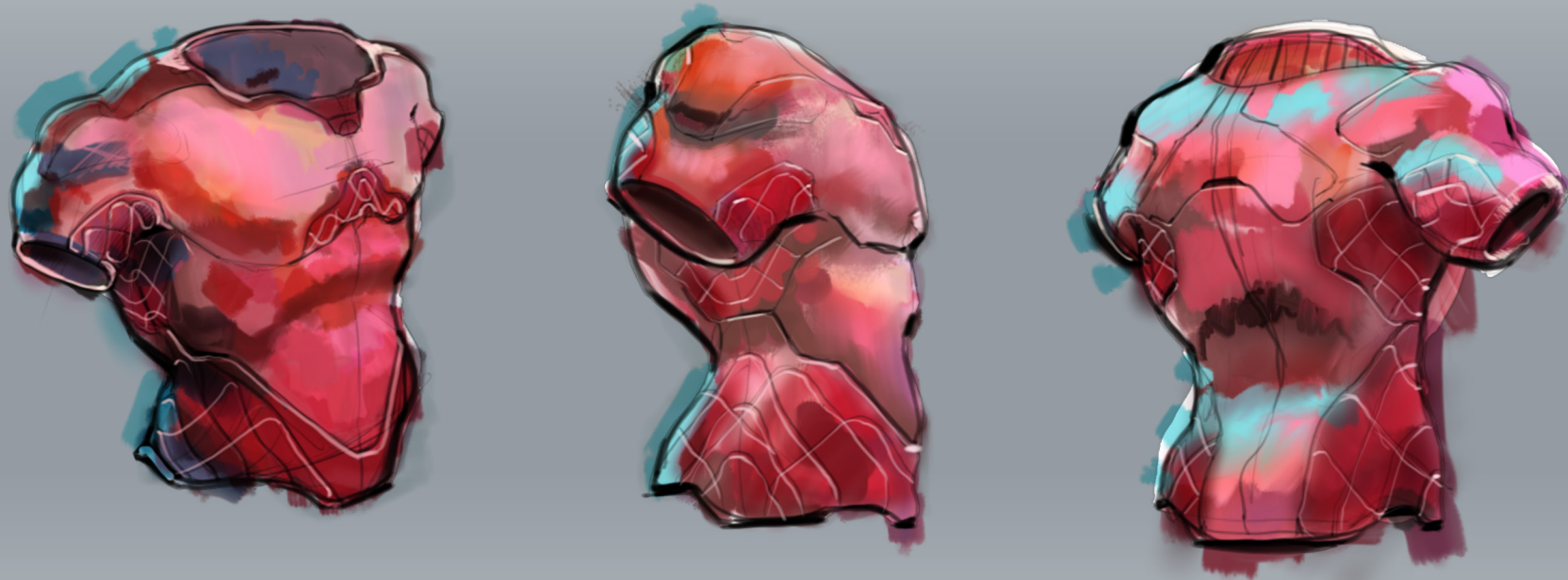


DIRECTIONAL PANELS FLOW RIGHT
INTO THE WAIST




RYAN
MOECK
2015

SUNFLOWER SUIT IDEATION
MASTER'S THESIS : MAY 2015

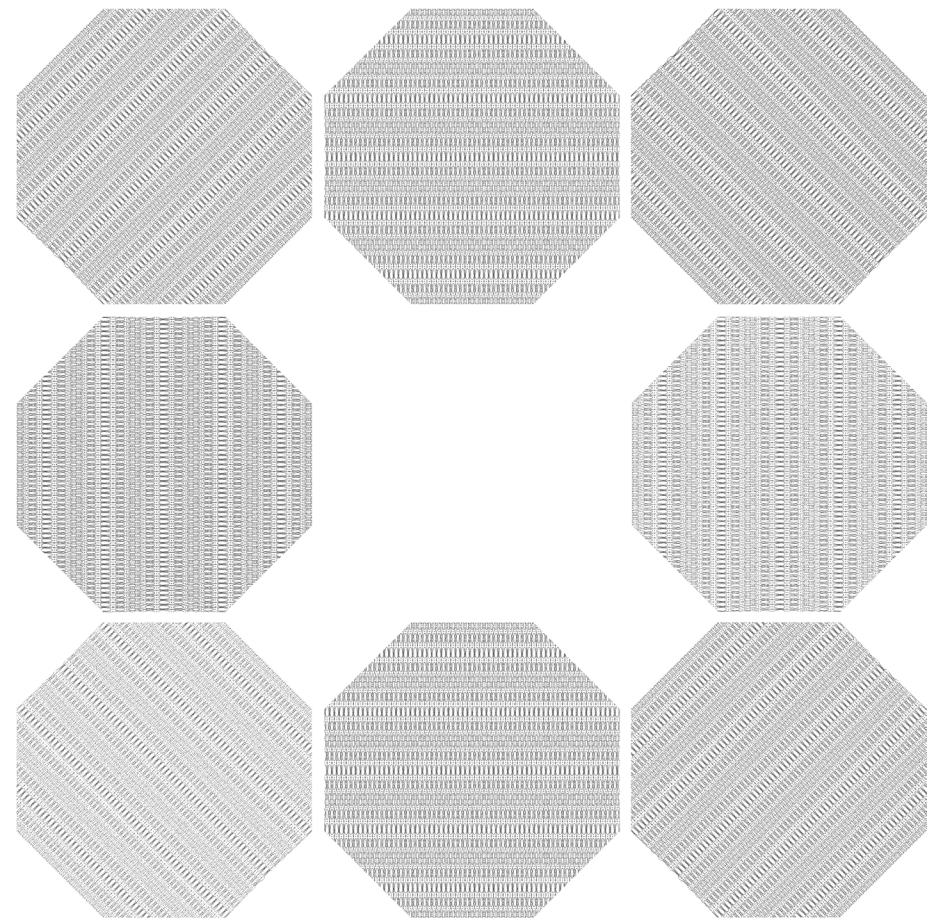


T. D. M.
MOECK
2015

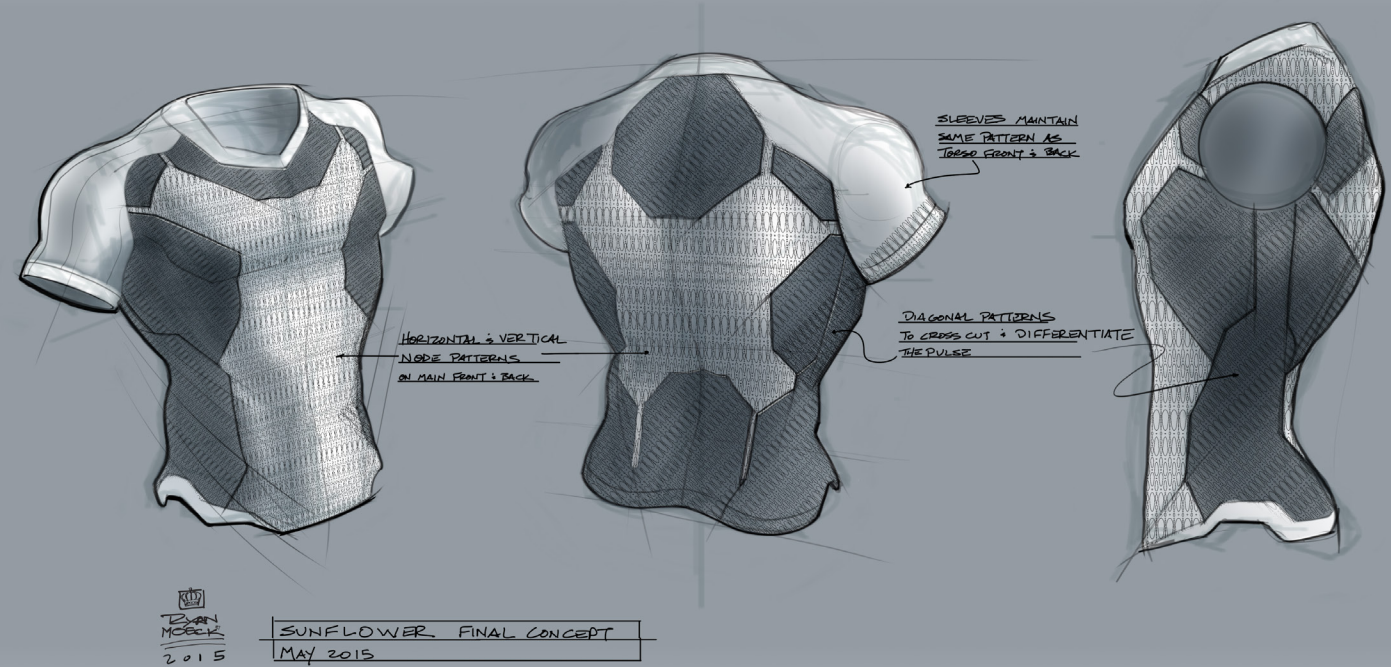
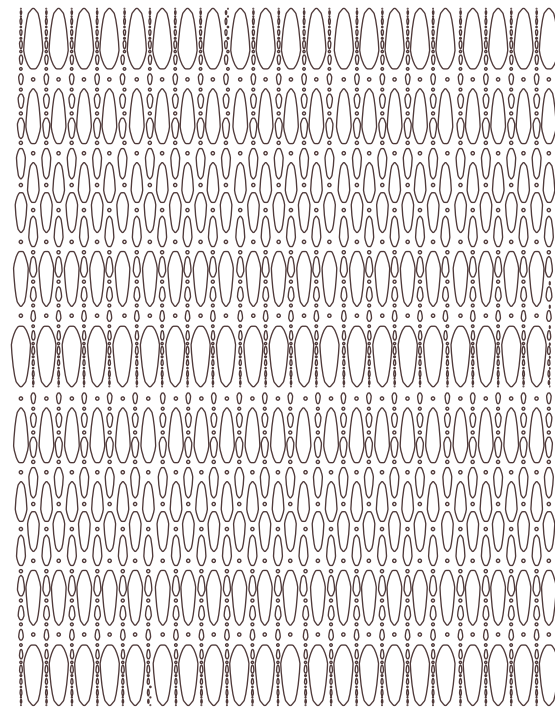
SUNFLOWER SUIT IDEATION
MASTER'S THESIS : MAY 2015



Node pattern concepts



Node pattern based on sunflower petal shape.



Final suit design

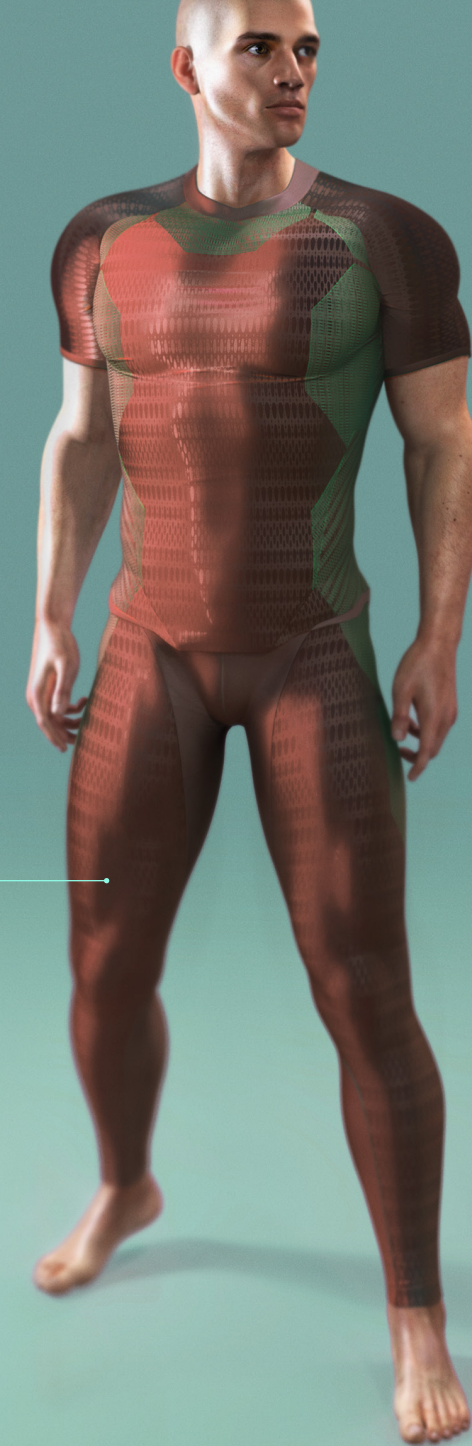
Concept Vision: Final Design



Meet Sunflower

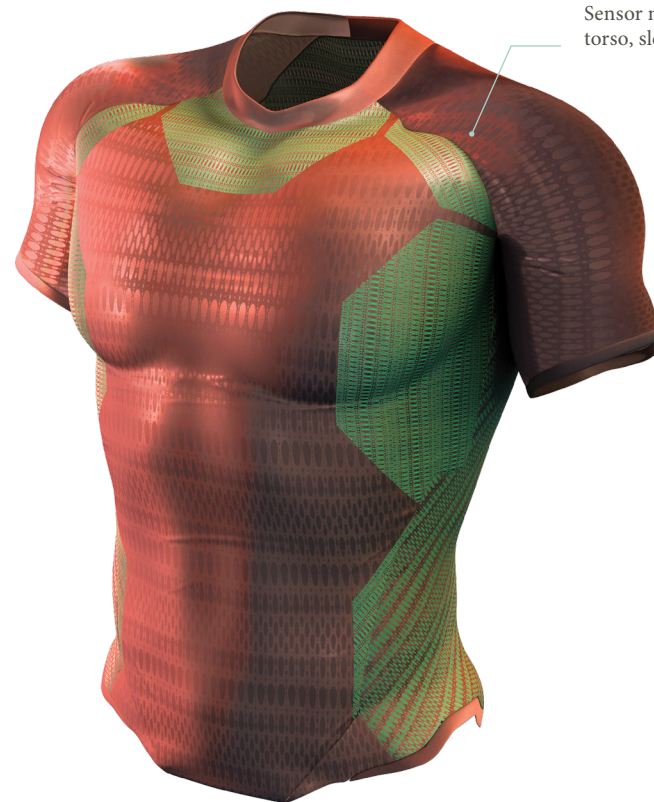
Tactile Navigational Bodywear

Sunflower is a tactile navigation system for low-vision environments. It consists of a wearable mesh of tiny sensors and actuators that constantly “pulse” toward the user’s destination, much like a sunflower follows the sun.

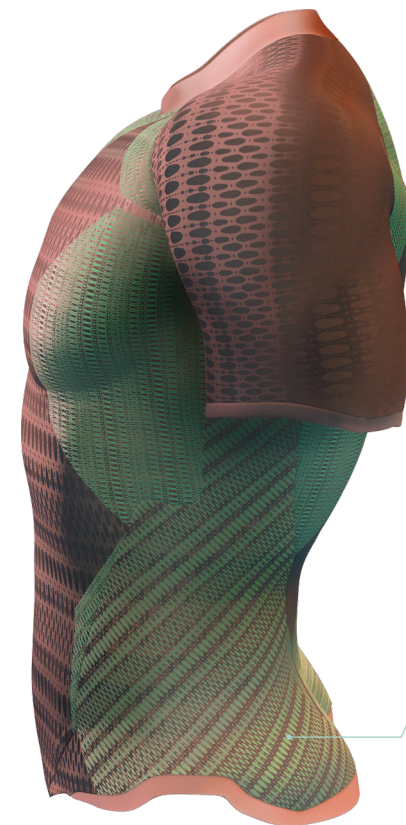


82

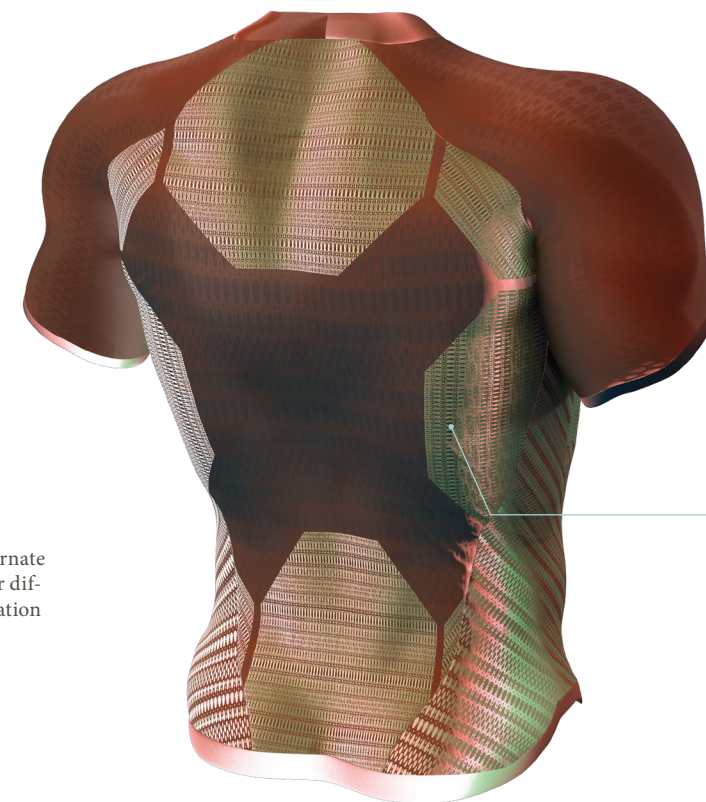
Final Design



Sensor mesh network covers torso, sleeves, and legs

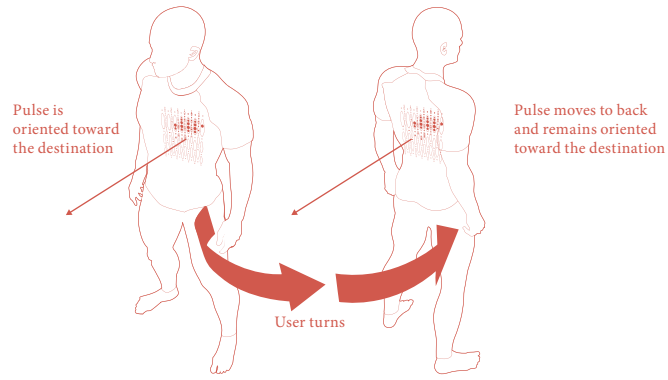


Directional panels with alternate node layout pattern for clear differentiation between destination and decision point pulses



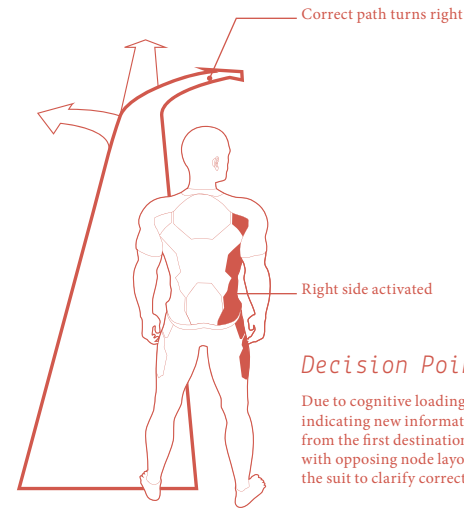
Pulse signals move seamlessly from front to back in any direction

How It Works



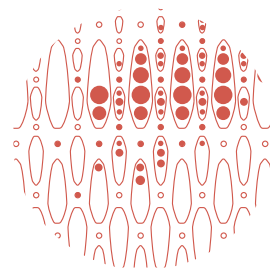
Destination Lock

The pulse is a small localized area of firing actuators that are oriented toward the destination. The pulse moves freely across the body to maintain destination lock no matter the user's orientation.



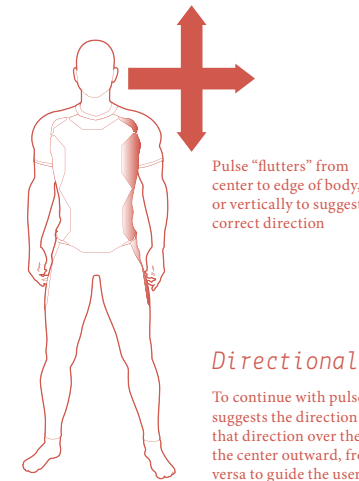
Decision Point Assistance

Due to cognitive loading limitations, a second pulse indicating new information should be differentiated from the first destinational pulse. Directional panels with opposing node layouts are located on the sides of the suit to clarify correct paths at decision points.



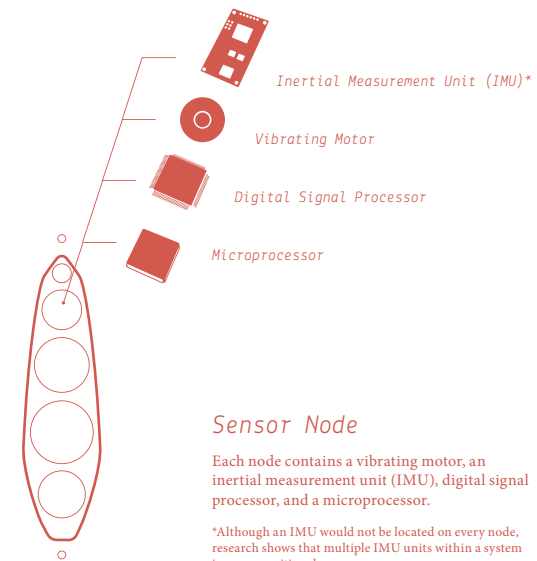
Pulse Swarm

Nodes cooperate to relay data for the network. Suit actuators fire in a swarm pattern, moving the pulse fluidly across the body.



Directional Assistance

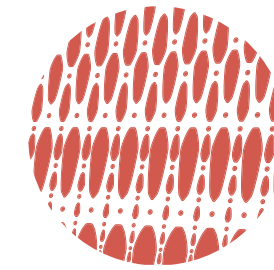
To continue with pulse differentiation, Sunflower suggests the direction to go by actually moving in that direction over the body. Actuators flutter from the center outward, from leg to shoulder, or vice versa to guide the user in the correct direction.



Sensor Node

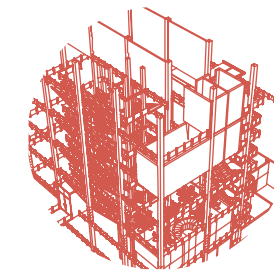
Each node contains a vibrating motor, an inertial measurement unit (IMU), digital signal processor, and a microprocessor.

*Although an IMU would not be located on every node, research shows that multiple IMU units within a system increase positional accuracy.



Sensor Mesh Network

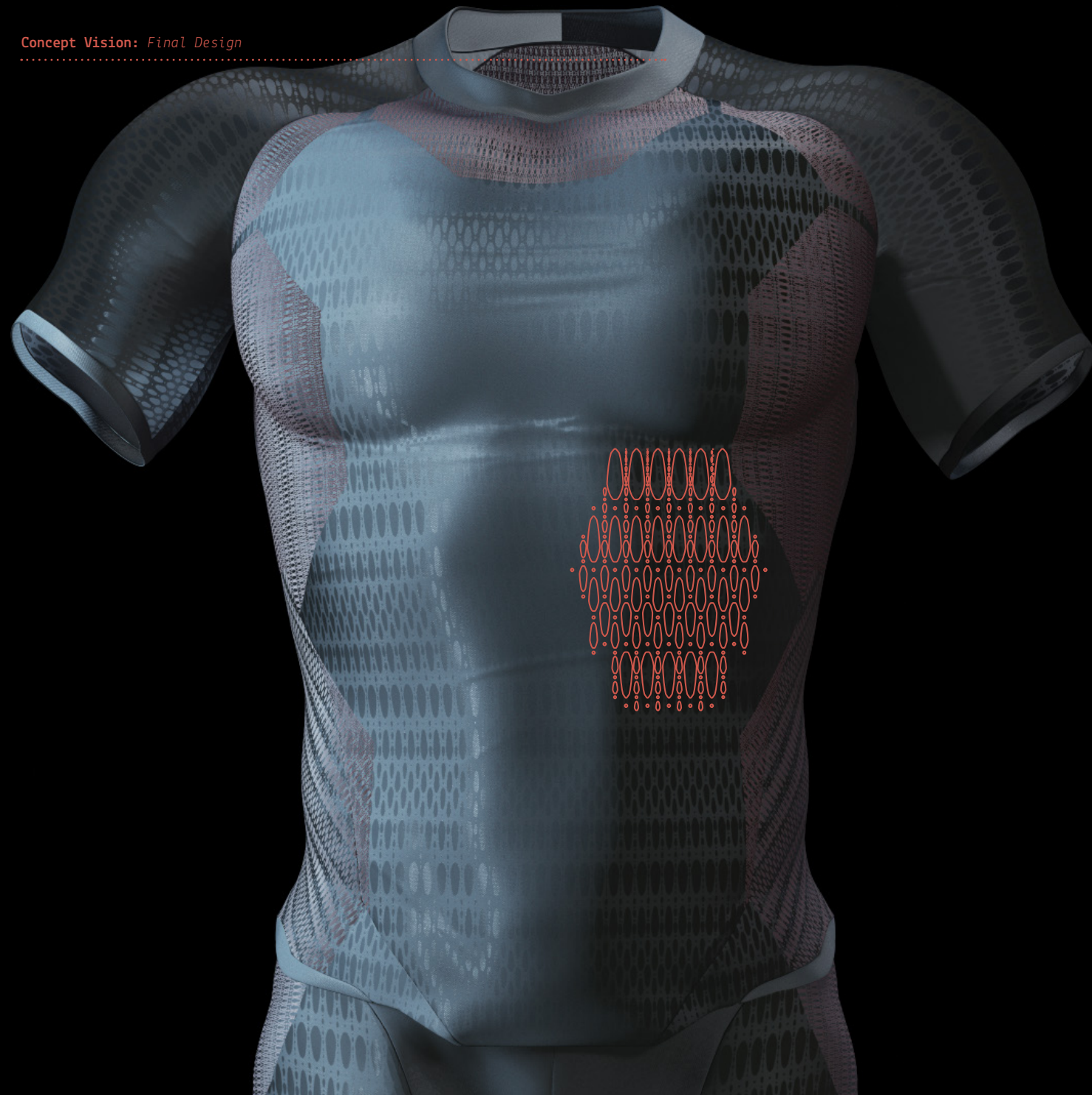
The Sunflower system consists of a sensor mesh network embedded within the fibers of the garment to provide near universal coverage of the body.



3D Floor Plan Data

Sunflower derives its information from scanned 3D floor plan data. Building-specific digital landmarks and dimensions drive the system to know where the destination is, and when and where to turn.

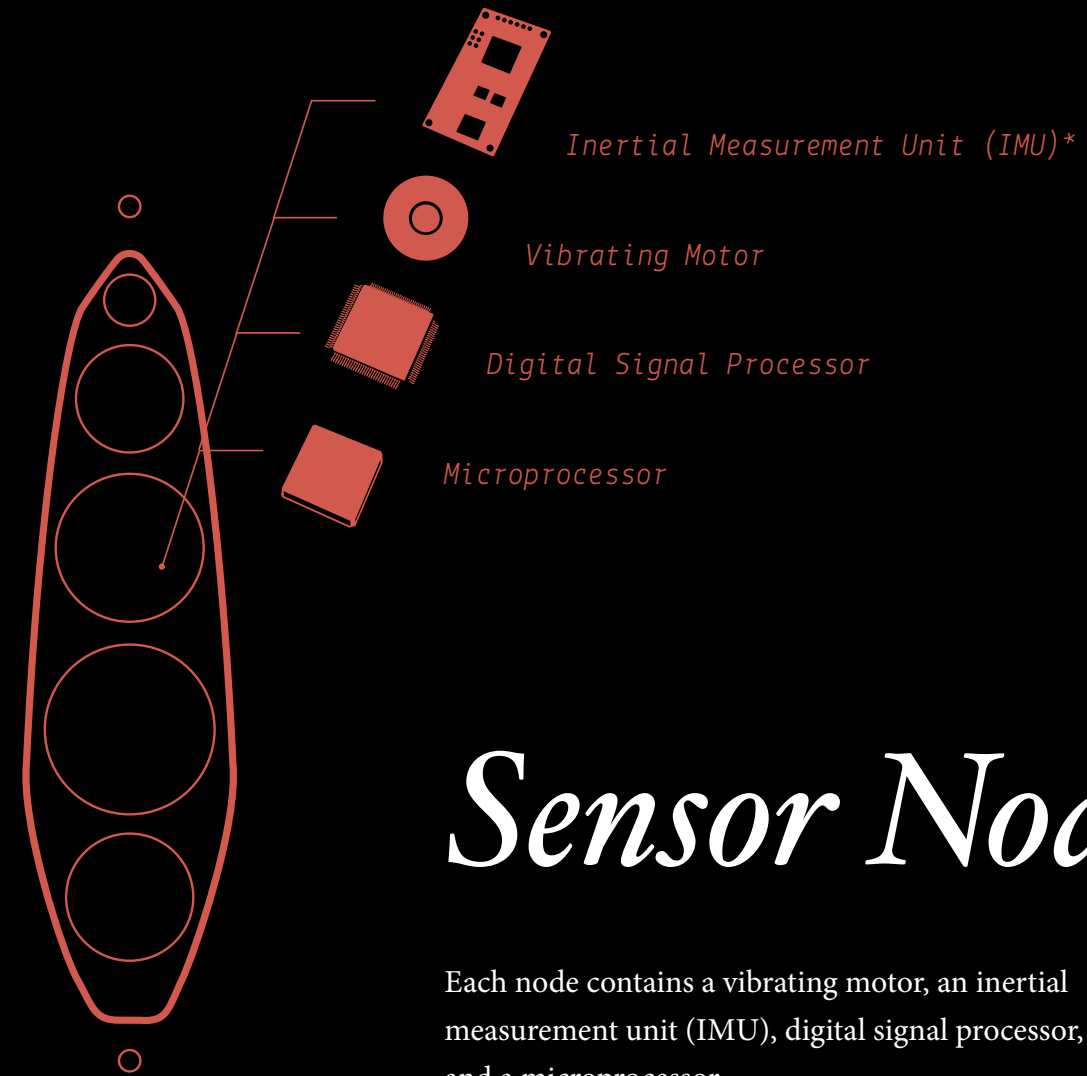
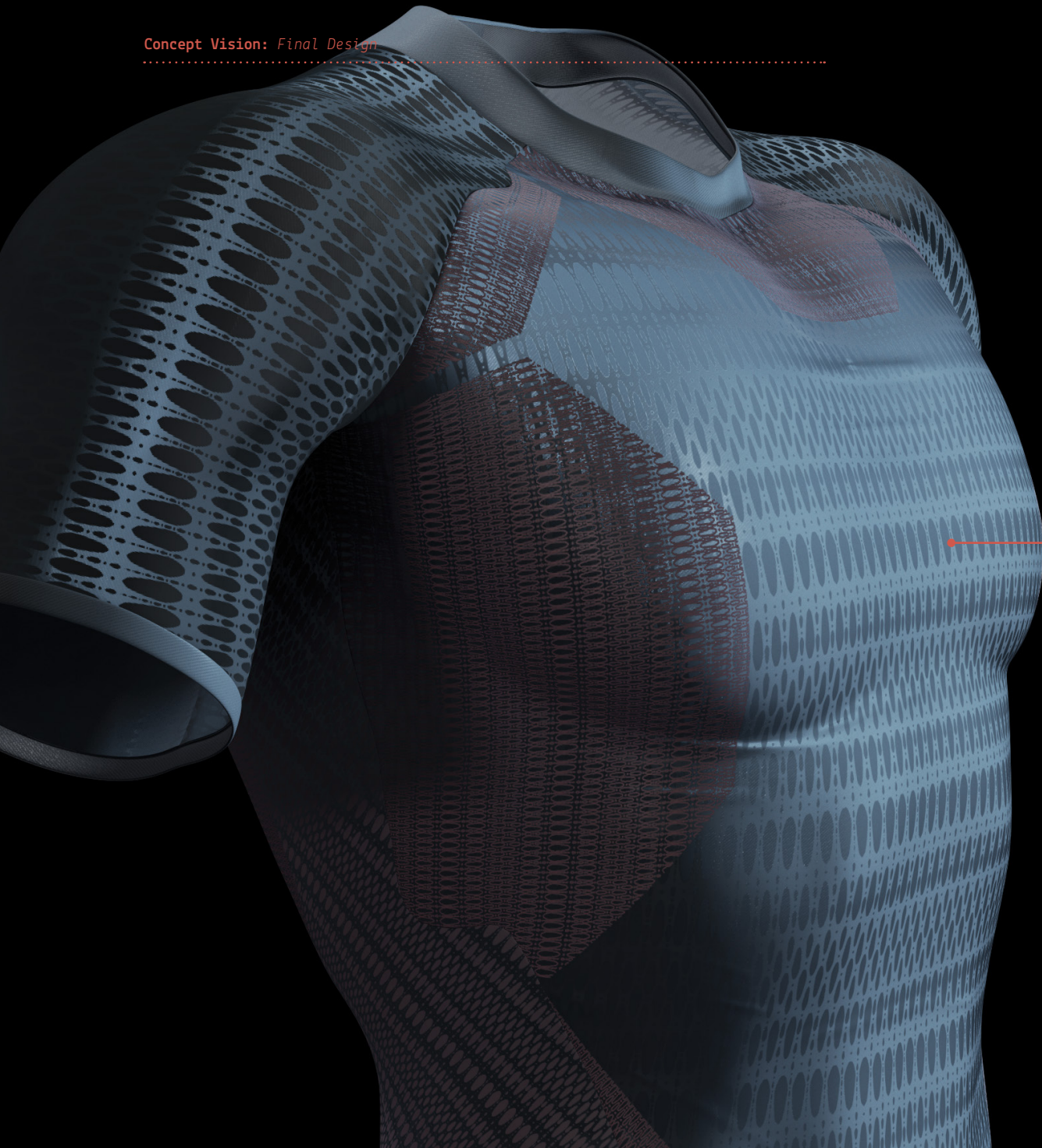
Concept Vision: Final Design



Sensor Mesh Network

Sunflower consists of a sensor mesh network embedded within the fibers of the garment to provide near-universal coverage of the body.

Concept Vision: Final Design



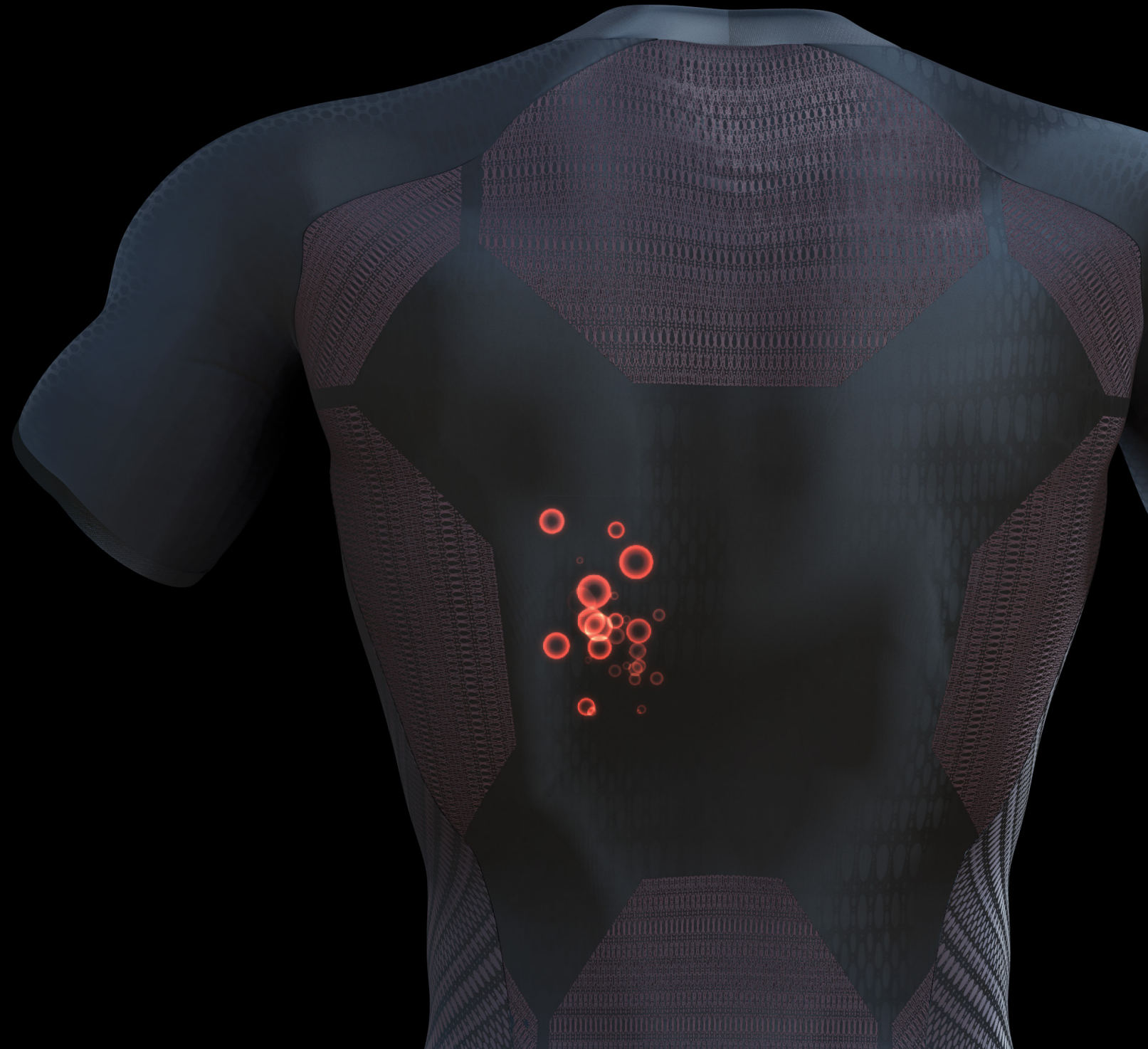
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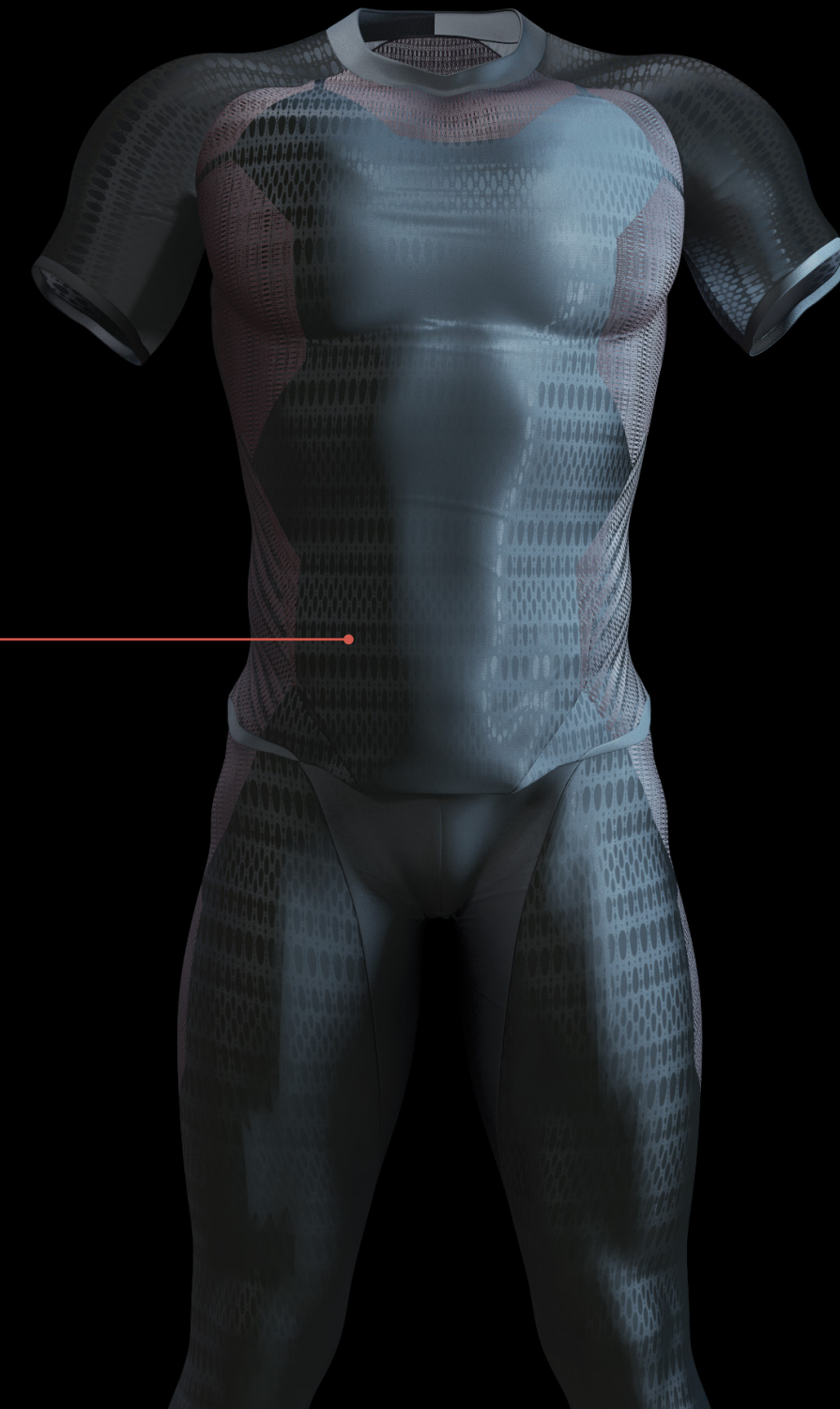
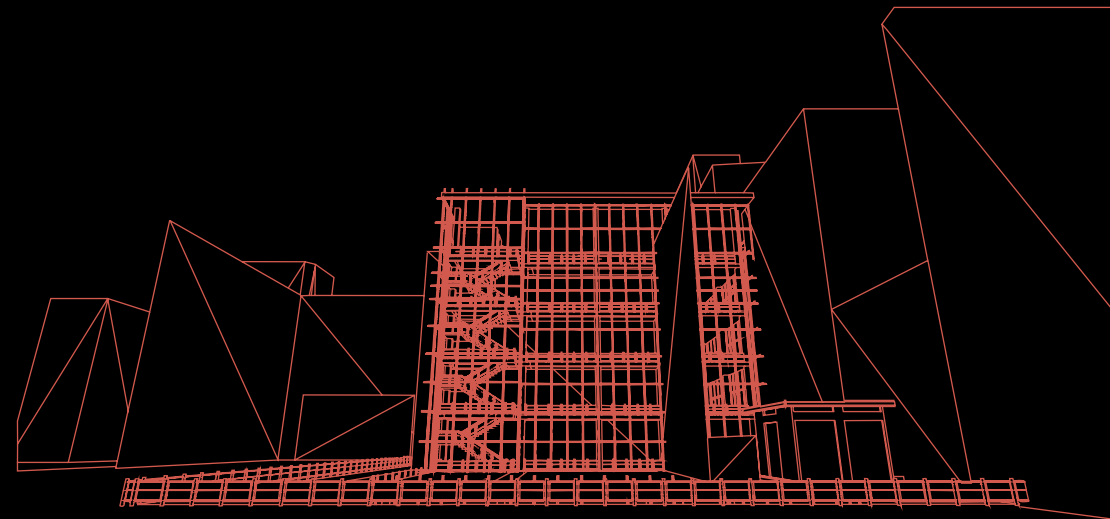
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Pulse Swarm

Nodes cooperate to relay data for the network. Suit actuators fire in a swarm pattern, moving the pulse fluidly across the body.

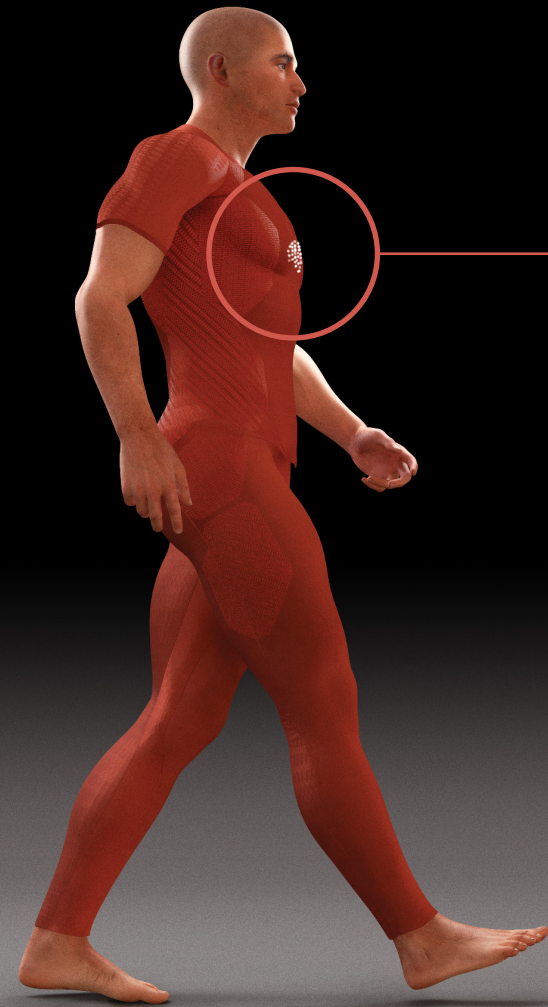


Concept Vision: Final Design



3D Floor Plan Data

Sunflower derives its information from scanned 3D floor plan data. Building-specific digital landmarks and dimensions drive the system to know where the destination is, and when and where to turn. Current developments, such as Google's Project Tango, show that we are not far off from this sort of technology.



Destination Lock

The pulse is a small area of firing actuators that are oriented toward the destination at all times. The pulse moves freely across the body to maintain destination lock no matter the user's orientation.

Decision Point Assistance



Panels with opposing node layouts on the sides of the suit clarify correct paths at decision points.



What makes this concept possible is the tiny size of the sensor/actuator nodes. Similar to the pixels in a screen, the actuator nodes fire together in swarm patterns to generate a pulse that is sensitive enough to detect small changes in user orientation. Thus, the pulse can feel smooth and seamless across the body as the user changes direction, rather than jumping from section to section, if larger nodes were used.

Ideally it works in conjunction with scanned 3D floor plan data by locking on to the hard global coordinates and pulsing toward it like a compass points due north, or as a sunflower points toward the sun, regardless of the orientation of the user.

Obviously a system like this would have countless uses and benefits beyond navigation. For the scope of this project, however, it will focus solely on tactile navigation in low-vision environments.

To discover how this concept might be applied in the real world, let us consider it in use in three different low-vision scenarios.

1_ Firefighters in burning buildings

2_ Families in crowded public places

3_ Students on complicated campuses

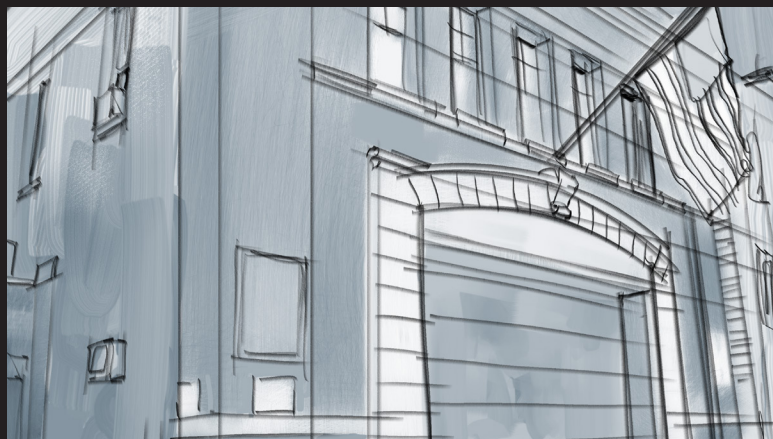


Scenario

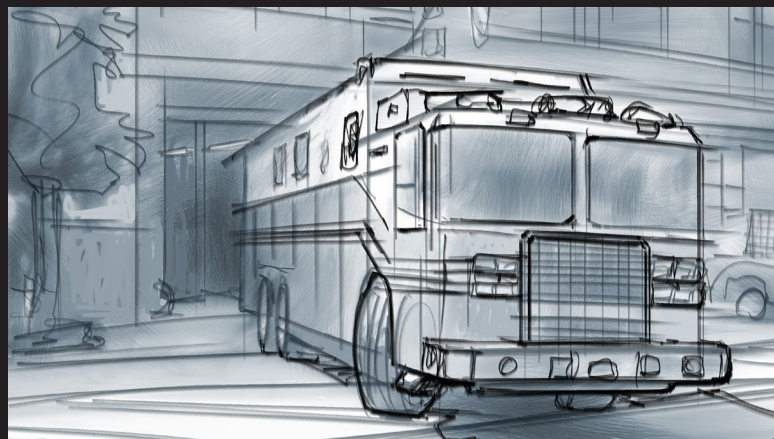
01

Firefighters in Burning Buildings

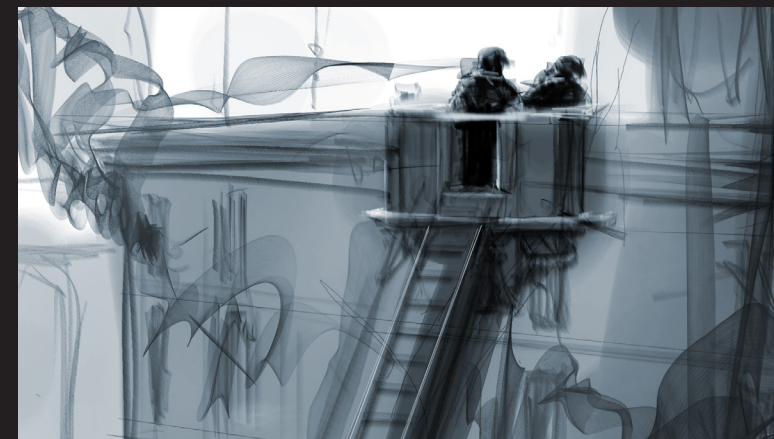
102



Firefighter Tom Sanders has been stationed at South King Fire and Rescue Fire Station 62 for five years.



Tom and his crew get the call—a two-alarm fire on 2nd and Pike.



Sanders and Hodges go up the lift . .



. . . and enter with forcible entrance tools.



Tom and his crew arrive at a call downtown to find fire coming from what appears to be a roof vent on the south side of the roof. They are unsure of the fire loading inside the building, but know these types of buildings are often used for storage, and the contents are unknown. They need to get men in there to assess the situation and check for signs of life.



The incident commander accesses the scanned 3D floor plan data for the building on his tablet. He looks for the easiest way into the building based on marked entrances in the 3D data versus where the fire appears to be. He and his crew determine that the third floor window is going to be the best way to proceed.



They are wearing the Sunflower system underneath their firefighting gear.



A pulse on their gear is oriented toward the window they entered through. No matter which way they turn, the pulse remains pointed that direction.

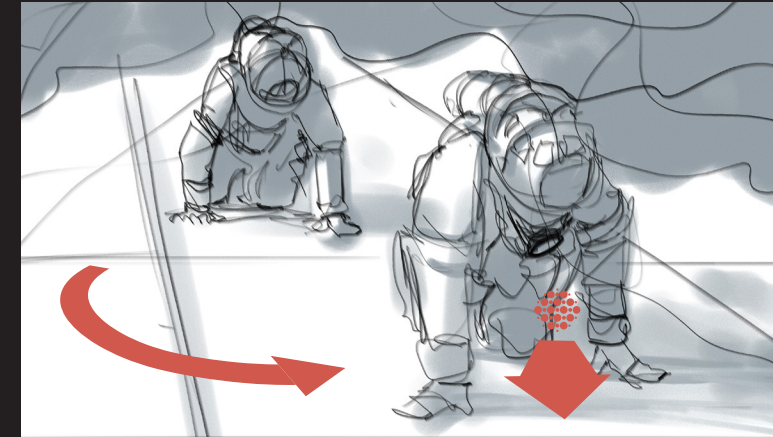
Scenarios: 01 _Firefighters in Burning Buildings



They meet light heat and thick gray smoke three feet off the floor. At this point, visibility is about 14 feet. As they continue to crawl forward, then to the left, they notice the heat beginning to increase. They advance to a storage area with heavy smoke and moderate heat.



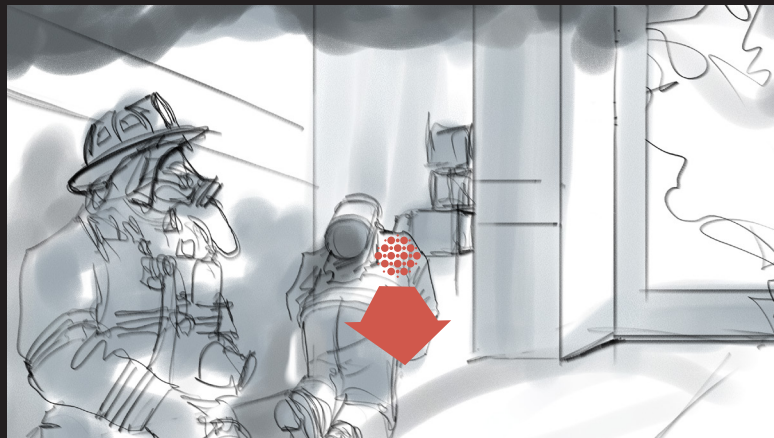
They extend a hoseline and apply water to the fire.



Completely blinded they turn and follow the pulse through the smoke.



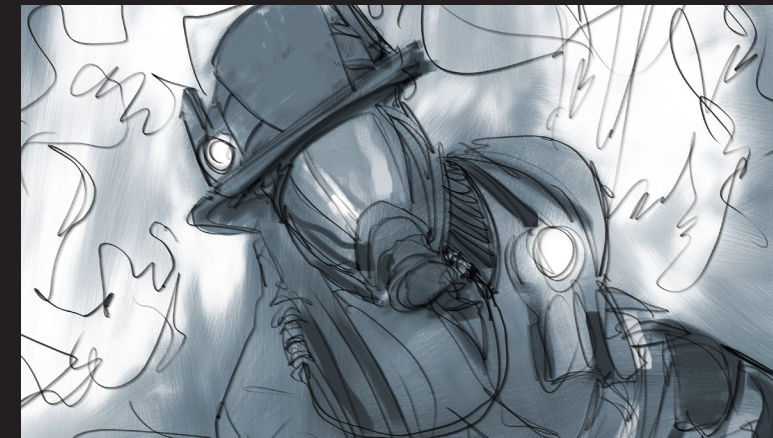
Less than ten seconds later, they hear the floor collapse in front of them, and nearly fall into the hole.



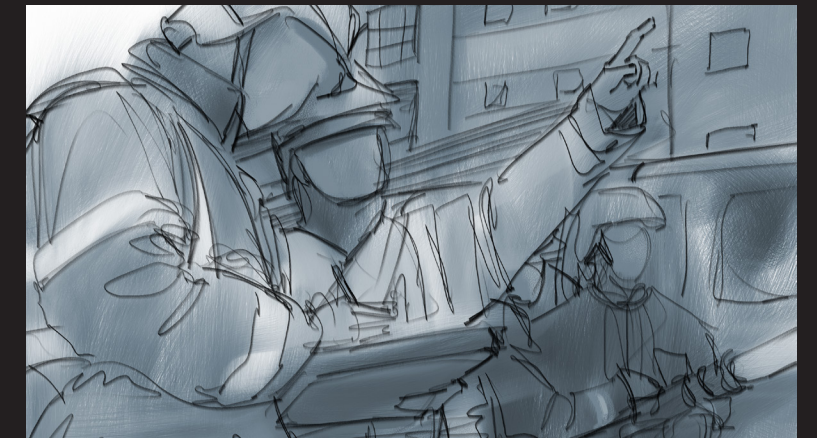
Although the prevailing unwritten rule in fighting fires is never leave the safety of the hose, Sunflower allows them to let go and check on a box near the back of the room that the hose cannot reach. They need to determine whether there are hazardous materials in there.



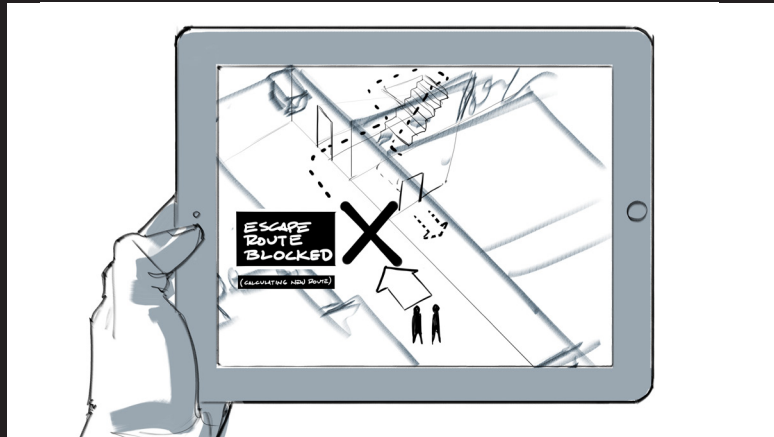
Knowing where their exit point is, they get low and crawl through the hallway.



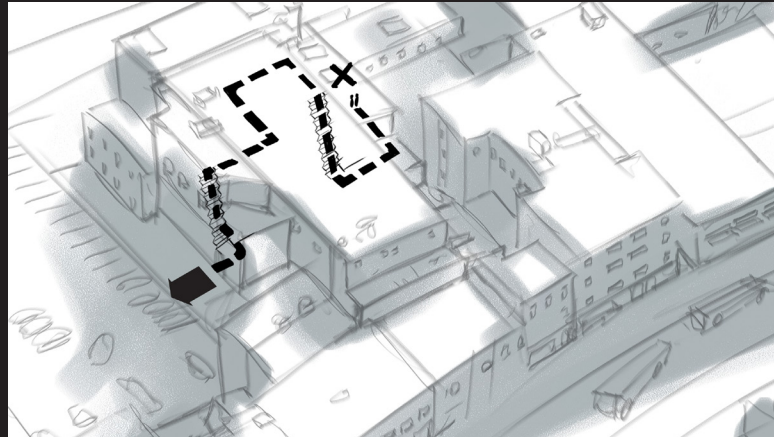
Grabbing the remaining flooring, they pull themselves out, feeling the intense heat on their legs. The hole appears to be about twelve feet deep and clogged with thick smoke. Seeing only black smoke and an orange glow with that kind of heat, they know this path is suddenly no longer an option. Sanders radios MAYDAY.



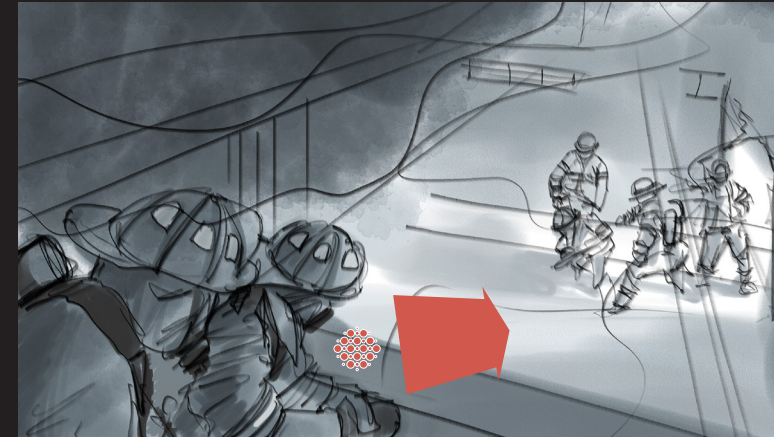
Outside the incident commander receives their mayday call and accesses the 3D floor plan on his tablet.



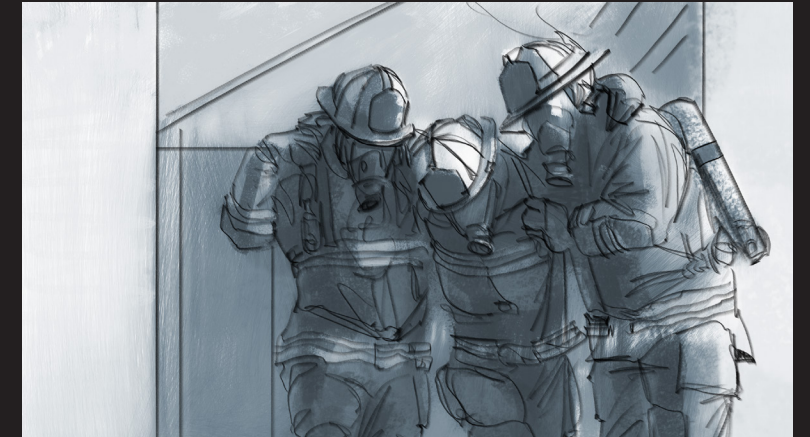
Based on Sanders' information, he recognizes that the original escape route is cut off and finds a new route.



He sets the pulse to target the new exit—a back door on the first floor that appears to be untouched by the fire. His men would be able to get there by avoiding the original path that they retreated from in the first place.



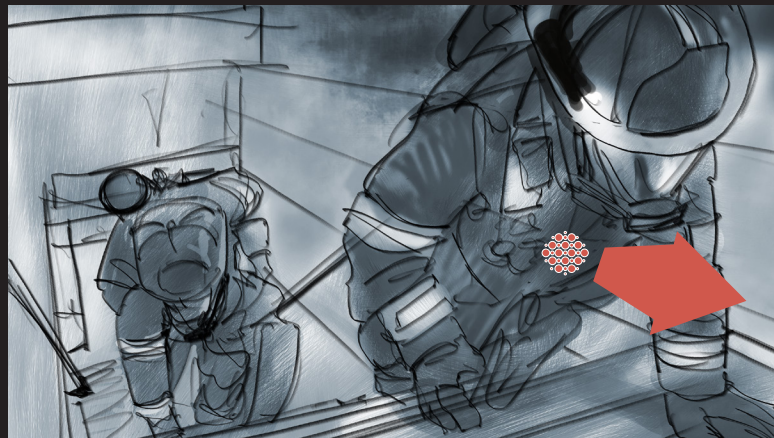
They can see the back door and another rescue unit entering there to retrieve them.



Sanders and Hodges are pulled to safety.



Sanders and Hodges feel the pulse swing from their sternum to the back of their right legs. They know that the destination is on the floor beneath them because the pulse is on their legs instead of their back and shoulders.



Following the pulse, they inch their way to the stairs and make a break for it.



Scenario
02

Parents with Children in Crowded Places

110

Scenarios: 02 _Parents with Children in Crowded Places



Sadie Lewis and her three children, ages 10, 7, and 4, are visiting Disneyland for the first time. Unfortunately they are there during peak season, so the crowds are dense.



They arrive at Main Street, USA and head north to Adventureland to attack everything clockwise.



She sees some princesses off to her left and, giggling, takes off to meet them.



Sadie does not immediately notice the pulse that began on her left leg when Zoe got more than ten feet away from her.



They get in line for the Jungle Cruise, and estimates say that it is about a 45-minute wait. Four-year old Zoe wants no part of this line—or the Jungle Cruise.



Meanwhile, Sadie has been trying to get seven-year-old Logan off of his six-year-old brother, Elijah. They are wrestling in line and just kicked the nice senior citizens in front of them. With these boys screaming and causing a scene, Sadie is already at her wits end.



As Zoe gets further away, the pulse increases in size and suddenly Sadie freezes, then panics. She knows right away that Zoe is missing. She frantically looks around. . .



. . . and takes off in the direction of the pulse. . .



... but cannot see over the sea of tourists. She has to go this one by feel.



Dragging Logan's hand in one hand and Elijah's in the other, with bags over her shoulders, she scampers in the direction of the pulse.



The pulse begins to lighten up and Sadie begins to breathe a little bit slower. She knows that she is getting warmer; Zoe is not far from here.



She bears down in the same direction and can faintly hear that distinctive giggle.



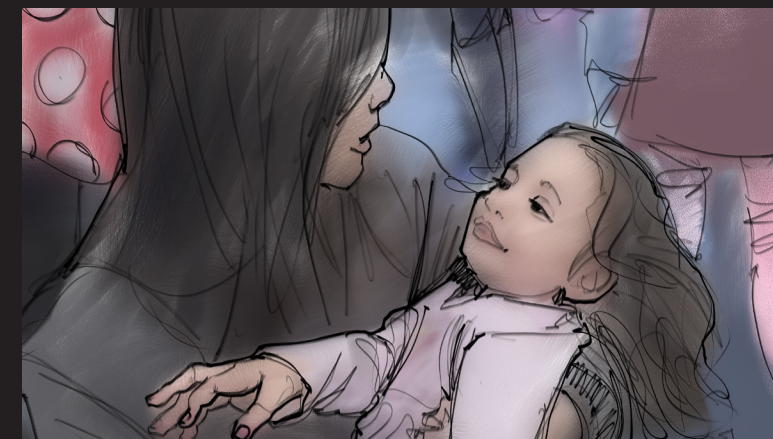
The pulse is locked on to Zoe. As she zigs and zags unpredictably, the pulse moves left and right across Sadie's legs. . .



... and she fishtails her path to match. The pulse slides over to the side of her left leg so she banks a hard left.



There is Minnie Mouse about fifty feet away, talking to a group of children.



Sadie bounds up, and scoops her little girl in her arms, tears streaming down her face. Reunited, Sadie is thankful she was able to find her daughter without losing her other boys in the process.



Scenario
03

Students on a Complicated Campus

116

Scenarios: 03_Students on a Complicated Campus



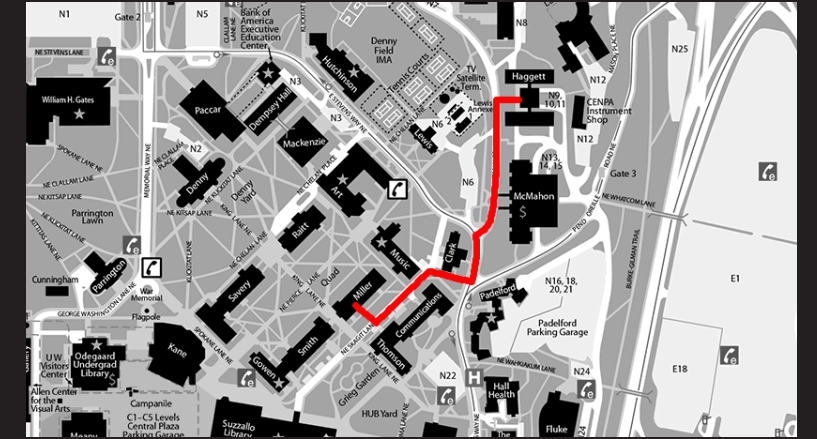
Meet Penelope Smith, a new freshman at the University of Washington who self-identifies as “directionally challenged.”⁷⁸⁰



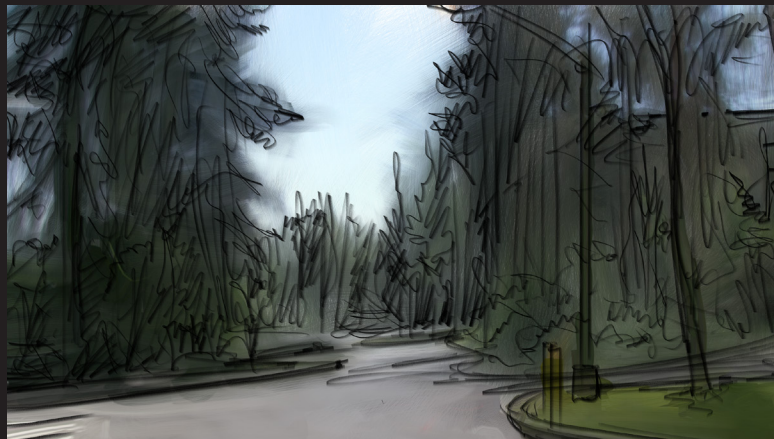
The campus is known for being difficult to navigate due to its organic and asymmetric layout. Many of the buildings look similar, can be confused for one another, and have wide distances between them.



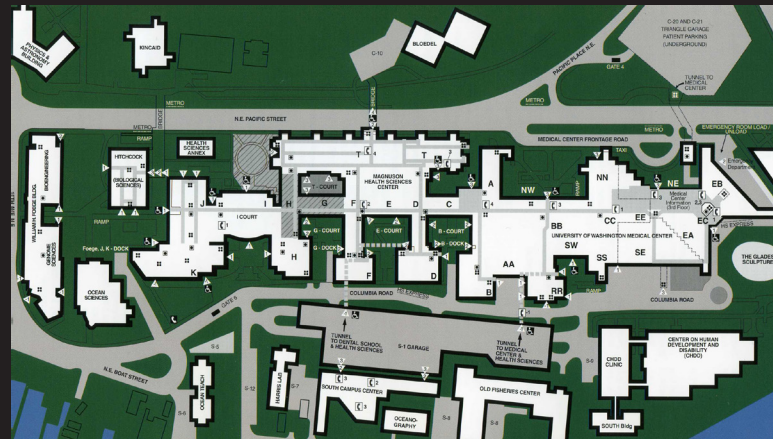
But today Penelope has a bigger problem. She has extreme tooth pain. . .



. . . and needs to move outside of the pathway of her normal routine and find her way to the Magnuson Health Sciences Building on the south side of campus.



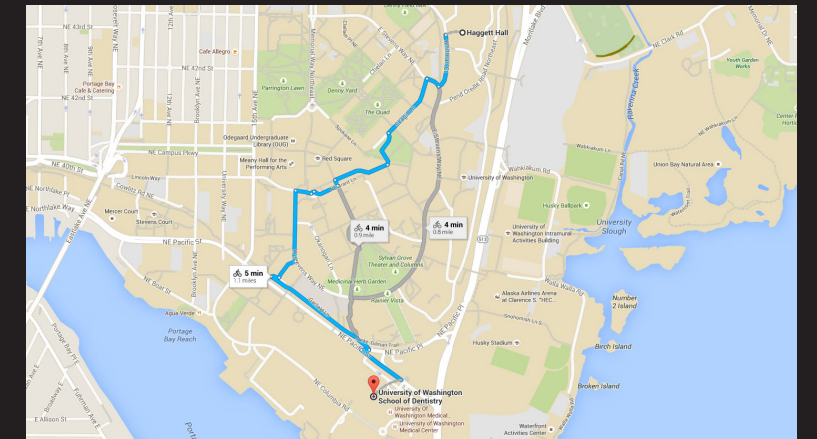
Trees obscure many of the taller landmarks making it hard to orient oneself at all times.



Building layouts are complex in their own right, and can be formidable to get through quickly. It took Penelope much of her first month at school to learn the just the layout of the campus and buildings where her classes were located.



The system recognizes her situation (student at UW), her location (UW campus) and locks her destination into the exact room, B-229, Magnuson.



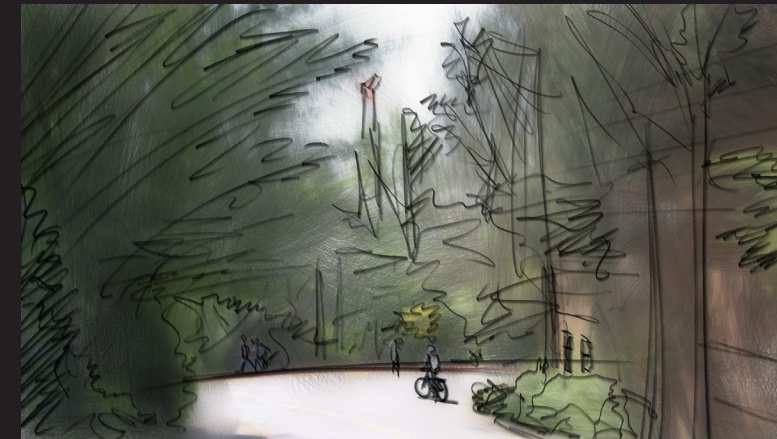
The GPS shows her a visual path to the building. . .



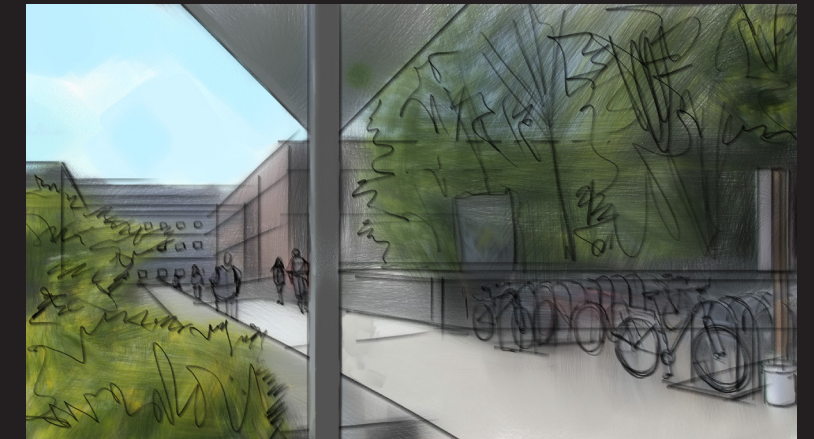
... and her Sunflower system pulses on her left shoulder.



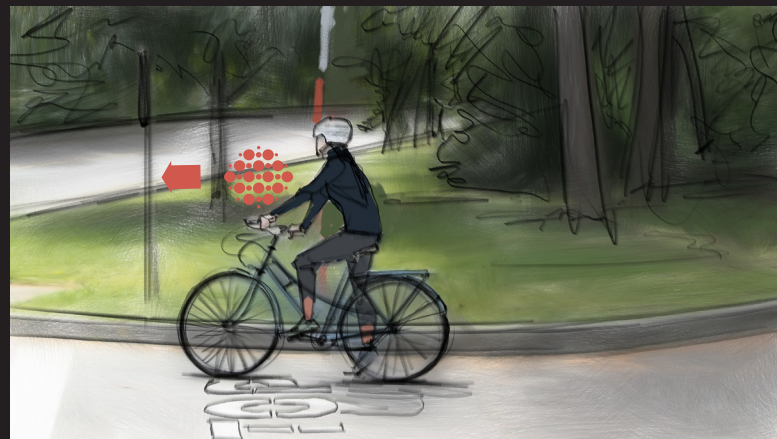
She gets on her bike and rides south.



She reaches the Burke-Gilman trail and can see the Magnuson Center through the trees. It is a massive building—the fifth-largest in the United States, and the largest university building in the world. It is clear to Penelope that getting there was only half the battle.



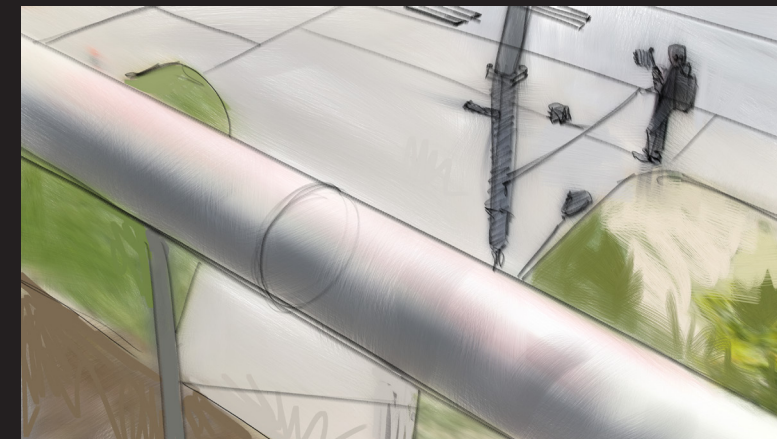
There is a bridge straight ahead that leads across Pacific street right into the building on the fourth floor.



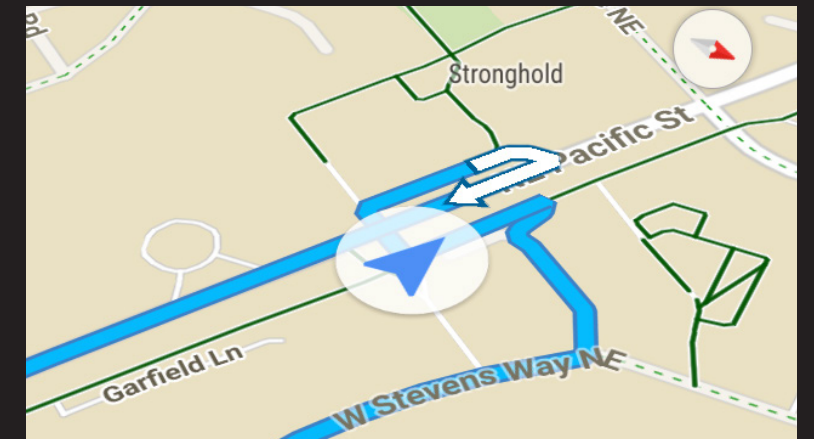
Along the way, as she turns left and right, the pulse remains locked on to the destination.



The constant feeling of the pulse on the front of her shoulders or torso allows Penelope to proceed with confidence on her bike with her phone tucked away in her pocket.



There is also a path that leads down to a street crosswalk.



Her GPS map shows a crossing of the street at this point, but it is visually unclear which one she needs to take.

Scenarios: 03_Students on a Complicated Campus



Fortunately, Sunflower has detected her indecision and changed the pulse vertically from her ankles to her shoulders in a repeating flutter pattern.



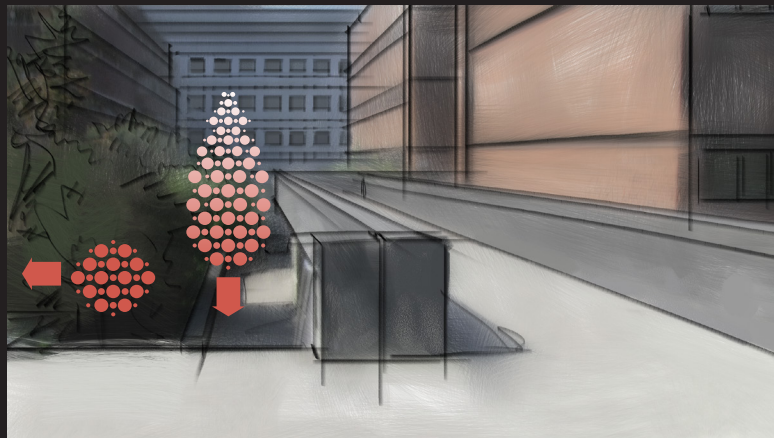
This signifies to her to cross the higher elevation of the bridge, rather than the lower street level.



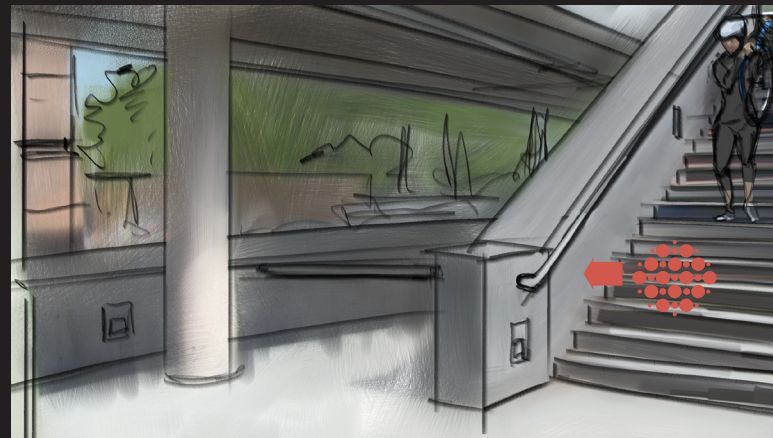
Penelope continues for several blocks on the south side of Pacific heading east toward the dental building. The pulse on her right front shoulder changes into a full-body flutter for three cycles, indicating that this BB-wing entrance is the one she wants. With three entrances to choose from along this street, this is not an insignificant notification.



She parks her bike and enters the building. At this point GPS is no longer viable, and Penelope's tooth is killing her. She needs to find the office fast.



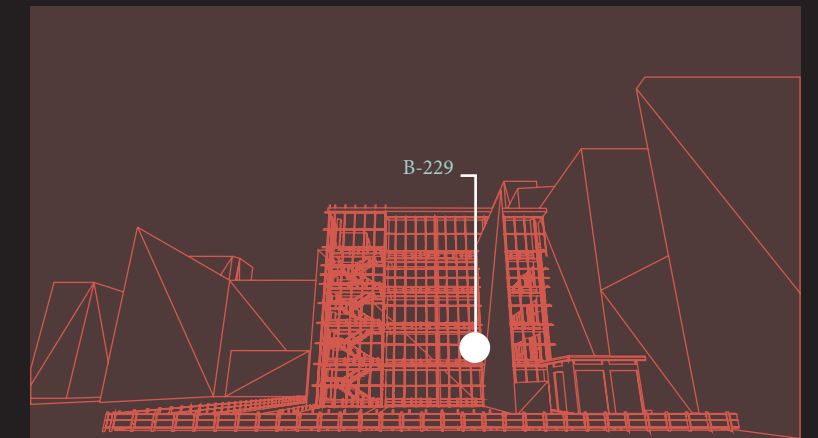
At the end of the bridge is a decision point: stay on the bridge and go to the building or down the stairs? Having a bike makes this less intuitive. Is she really supposed to carry her bike down the stairs? Sunflower flutters from her shoulders to her ankles signifying to go down the stairs.



Penelope heads down the stairs and east down Pacific.



The Magnuson is a famously entangled maze prohibiting quick access to much of anything.



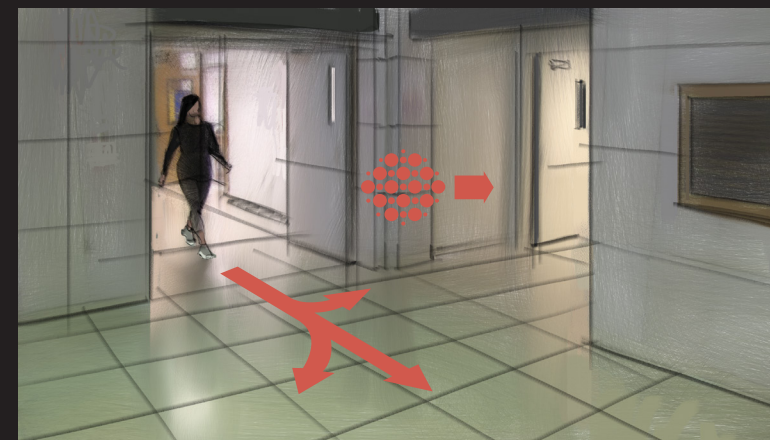
But Penelope's Sunflower system has access to the scanned 3D floor plan and knows exactly where B-229 is. It sends a notification to her phone to audibly warn her that she is entering on the third floor, not the first floor, which might be assumed due to the street-level position of the entrance.



Penelope reaches her first decision point right inside the main doors.



Sunflower flutters right and Penelope follows suit.



Penelope reaches a wide open decision point.



Sunflower flutters to take her left.



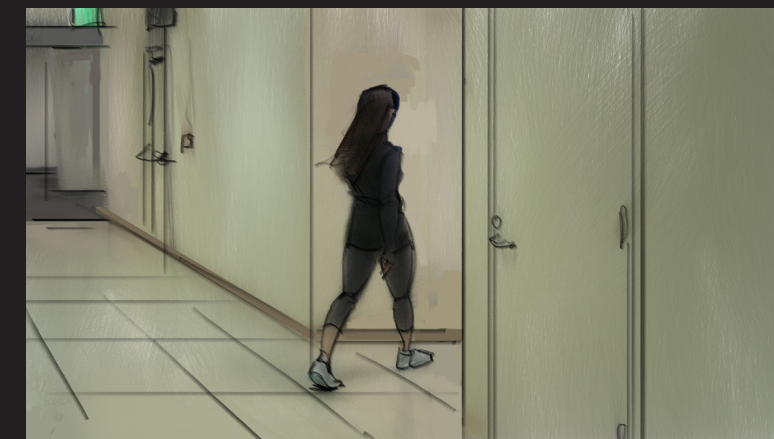
Penelope heads toward the Pacific Elevators. Penelope moves forward relying on both the consistent destination pulse, and the intermittent break patterns that fluctuate right before she reaches a decision point. If the system knows there is a path fork, the system flutters in the optimal path direction.



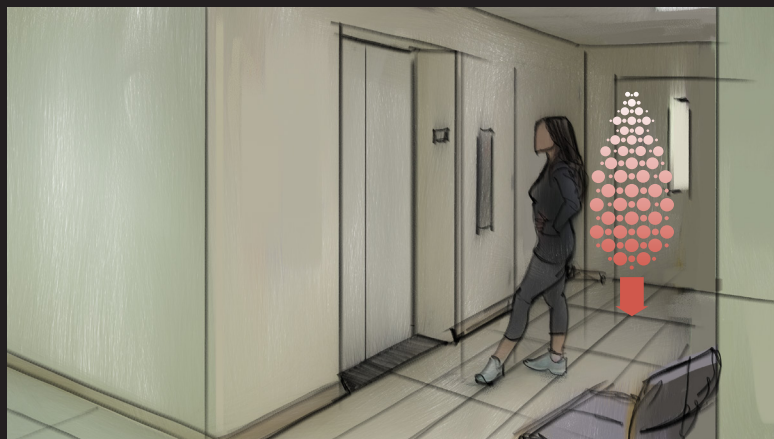
Penelope passes three more decision points with ease. Each time the decision might have been difficult, Sunflower breaks the pattern to make it nearly certain which direction she needs to go.



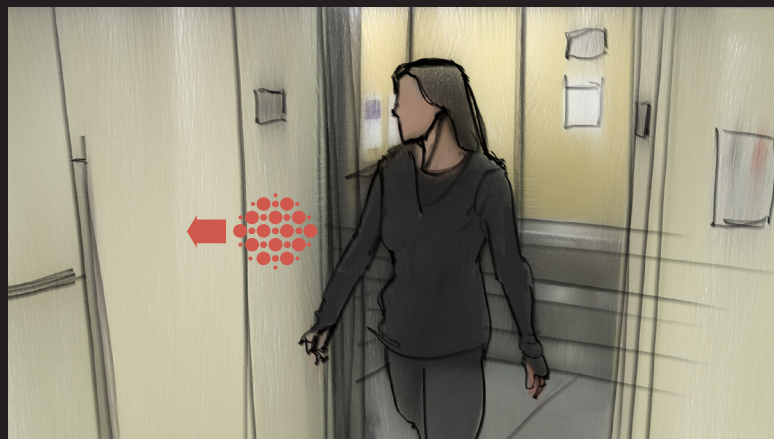
Urgent care has moved, which is different from the signs posted on the walls. But Sunflower knows. . .



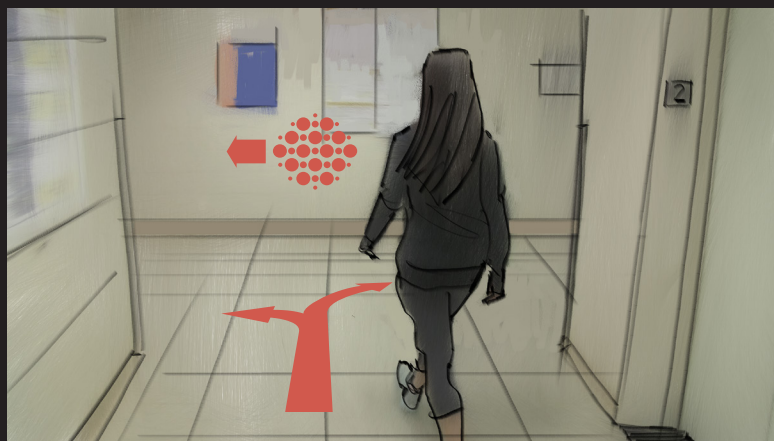
. . . and flutters from left to right to go around the corner. . .



... and from shoulder to ankle to take the elevator.



After the elevator the system flutters right.



System flutters left.



She finally reaches B-307, much faster than if she were on her own.
Although Sunflower got her there more quickly, she still has to fill out new patient paperwork.

Conclusion

This presentation of Sunflower, a tactile navigation system for low-vision environments, is a case-in-point example of a plausible vision for the future. It is intended to help coordinate the future efforts of scientists, researchers, and designers by establishing a concrete visual example which all can criticize, build upon, and unitedly move forward with. It began as an exploration of the abstract prompt, how might we feel 3D space? Although this proposed technology does not yet exist, through analog user tests I derived enough data to drive this exploration into a design that should comfortably and effectively help firefighters in burning buildings, families with children in crowded places, and students on a complicated

campus achieve their goals through tactile senses. By bringing computers in direct contact with the body in such an extensive and globally interactive way, Sunflower would obviously have countless uses beyond that of the scenarios here illustrated. It certainly would go beyond just navigation. But that is the purpose of a plausible vision. By exploring scenarios in a believable way, our imaginations naturally take over to see what else this might enable us to do.

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