

Final Report Title Page

TITLE: vizHOME: A context-based health information needs assessment strategy

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Structured Abstract

Purpose: The purpose of this project was to explore how household context shapes planning for, and performance of, personal health information management (PHIM) tasks.

Scope: This 5-year research project captured and explored the visible physical aspects of the home environment that influence PHIM. Through a series of home assessments, laboratory studies, and a field survey we aimed to answer two questions: (1) Which features of the home context shape PHIM? (2) To what extent do task factors and personal characteristics alter the influence of the household context on PHIM?

Methods: The project consisted of five sub-projects which utilized field assessments, design workshops, lab studies and field studies. These data collection measures were undertaken both in physical environments (i.e. real homes) and virtual reality. Participants in the first four phases of the study were home-dwelling individuals who had been told they have diabetes and were known to have substantial information management demands. Over the course of the project over three hundred participants' data were included in analysis.

Results: It was found that medication management is a very decentralized process and the locations for performing common tasks varied greatly depending on the affordances in the homes. In this regard it is critical for health care providers to evaluate the environment in which an individual will perform PHIM and recommend strategies that are tailored to the environment and the individual. The techniques developed for use in vizHOME and the insights generated from the project created additional products in the field of healthcare and beyond.

Keywords: Personal Health Information Management, Health in the Home, Virtual Reality, 3D Scanning.

Overview

The purpose of this project was to explore how household context shapes planning for, and performance of, personal health information management (PHIM) tasks. PHIM is defined as cognitive and behavioral tasks that people do in an effort to achieve their health goal(s). Examples of PHIM include such things as: recording symptoms; communicating with clinicians; determining when and how to take or reorder medications; monitoring symptoms and health states; and seeking and/or making sense of health information that may be obtained in discharge summaries, health-related web sites and clinician-provided handouts. Frequently people undertake PHIM at home, and the home's physical features such as storage adequacy, lighting, privacy, and proximity of health information management tools influence the person's ability to recognize and complete these cognitive and behavioral tasks. We posited that knowledge of the household features that affect PHIM task performance can be used to better design technologies for PHIM. With our multidisciplinary team of clinicians, engineers, informaticians and computer scientists, we examined which contextual factors of the home influenced people's awareness of, and ability to complete, information-dependent self-management tasks. This work enabled us to better understand how context shapes information needs and uses – and provides preliminary guidance to computer solution designers and others about how technology must fit within homes. Ultimately, the long-term goal of this project is to improve individuals' self-management and health outcomes by informing the design and adoption of PHIM-supporting technologies that take into consideration useful features of the home context.

In this 5-year research project we captured and explored the visible physical aspects of the home environment that influence PHIM. Through a series of home assessments, laboratory studies and a field survey we aimed to answer two questions: (1) Which features of the home context shape PHIM? (2) To what extent do task factors and personal characteristics alter the influence of the household context on PHIM?

Overview of the Research Strategy

Institutional Review Board approval obtained for all Subprojects except SP2 where it was not required.

Sub-project	Main Activity	Method	Participants	Key Outcomes
1	Home assessment and rendering the homes in Virtual Reality (VR)	Field assessment	20 adults with diabetes and their dwellings	<ul style="list-style-type: none"> - 60 PHIM (3/house) task flow diagrams including one of each type: medication management, self-monitoring and general health information management - Replicate 20 dwellings in the CAVE - Matrix of similarity and difference across participants and PHIM tasks
2	Information Requirements Definition	Design workshops	Investigator team - 6 experts	<ul style="list-style-type: none"> - Preliminary List of household features that shape PHIM and appraisal of how these would be used
3	Requirements Validation	Lab study (In CAVE)	20 adults who self-identify as having diabetes	<ul style="list-style-type: none"> - Refined list of household features that shape PHIM with appraisal of feature by room associations
4	Refined Requirements Validation	Lab Study (In CAVE)	60 adults who self-identify as having diabetes	<ul style="list-style-type: none"> - Prioritized list of household features that are identified as useful for PHIM
5	Development and Testing of the Assessment of Context of Home Environments Inventory (ACHE)	Field Survey conducted by Survey of the Health of Wisconsin (SHOW) field staff	200+ adults subsampled from the SHOW panel	<ul style="list-style-type: none"> - Validation of incidence and prevalence of household features and comparison to SP1 homes
	vizHOME Product Dissemination	Website Development & Testing	N/A	<p>http://pages.discovery.wisc.edu/vizhome/</p> <p>Website describes the vizHOME project and makes products (point clouds of varying resolution, segmenting data, panoramas and video walkthroughs) accessible</p>

Technological Development

When the project was first envisioned, the plan was to convert scanned models (point clouds) into 3D meshes, a standard format for computer graphics. 3D meshes are a format that was known to work well in the VR environment and could be shared using traditional modeling software. Unfortunately, the team quickly realized that this approach caused a great deal of data loss, resulting in home environments that could not properly convey the environment as shown in the figure below.



This led the team to develop point cloud rendering software for virtual reality capable of conveying details of the environment. This process was difficult due to multiple factors. First, point cloud data is large and unorganized causing slow data access. Second, the data was too large to be rendered directly on a graphics card, so only a subset of the data could be rendered at once. Third, traditional non-immersive approaches to this problem use two different rendering techniques, a low fidelity highly interactive renderer when the user moves or interacts with the system and a high fidelity low interactive renderer when the user stays still. This approach was not viable because in nearly all modern virtual reality display systems the users' head is always moving with small positional and rotational changes. This continuous tracking allows correct perspective rendering of an environment which gives the user a greater feeling of presence within the VR scene. Accounting for these challenges, the team found that the few VR point cloud rendering solutions that exist were too slow and produced poor visual quality.

Given the goals of the project, the team decided that it was vital to develop a new point cloud rendering technique capable of providing both high levels of interactivity and high quality visuals. The team first developed a technique that utilized information about a user's previous view to create future viewpoints (Tredinnick, Broecker, Ponto, 2015). This approach enabled data to be reused, thus allowing a user's view to increase in fidelity over time. Next, the team utilized a hierarchical data structure and rendering technique to enable a viewpoint that progressively rendered from blurry to sharp over time (Tredinnick, Broecker, Ponto, 2016). Then the team combined these two techniques to enable fluid interactivity while maintaining visual quality (Ponto, Tredinnick, Casper, 2017). The refined version of this method renders models at photo realistic quality and highly interactive rates. This now patented technique (Ponto and Tredinnick, 2018) created a broad impact as described below.

Beyond the point cloud rendering system, several technical developments were created for the subprojects described below.

Subproject 1

Purpose

The purpose of SP1 was to conduct in-home assessments in 20 homes representing four main home types: detached, semi-detached, multi-unit, and mobile. The goals were to 1) enumerate Personal Health Information Management (PHIM) tasks routinely done by a primary respondent in each of the 20 houses; 2) develop profiles of the houses in terms of the physical aspect, layouts, and space orientation; and 3) through LiDAR scanning and point cloud data processing, generate a CAVE-viewable virtual model of each home.

Scope

The target population was community-dwelling adults who reported having diabetes and lived in urban, suburban, or rural regions of a mid-western state. Four home types: detached, semi-detached, multi-unit, and mobile represent a range of households and features. Adults with diabetes were selected because they must regularly engage in a number of self-care activities involving PHIM tasks; the disease affects many aspects of life, such as food selection, symptom monitoring, and exercise needs.

Methods

We employed a modified contextual inquiry process (an unstructured but purposeful interactive process situated in the person's natural environment) to conduct three home visits to each participant, with each visit lasting 2-3 hours. We employed semi-structured interview approach to learn about, characterize and consolidate the PHIM tasks in the three main categories (medication management, self-monitoring, and general information management) for data analysis.

Interviews were conducted by two study team members, an interviewer and a notetaker, and were audio-recorded. Participants responded to questions about their health concerns, self-monitoring, and self-management practices. A schematic map of the home was created to highlight its layout and focal areas for PHIM. Participants identified specific PHIM tasks in the locations where they performed them whenever possible. Additional data collected included general location of the home, respondent's global health rating, any perceptual or mobility limitations, others living in the home, presence of pets, and a home clutter rating. We also obtained full-scale 3D scans of the interior of each home. Data consolidation processes developed for the Health@Home model (Moen & Brennan, 2005) were utilized to characterize information management. Finally, we reviewed home maps to facilitate reconstruction of task activities across space and time.

Technical Developments

Subproject 1 required training of staff members on operation of the Faro Focus S120 LiDAR scanner, as well as proper acquisition of data after operating the scanner. The team developed best practices for each of these tasks and created a scanning protocol for all scanning team members to follow during operation of the scanner. The team executed this protocol in 20 recruited participant homes and 3 confederate homes. The confederate homes allowed for testing and revising of the developed methodology prior to performing the scanning within homes of actual participants.

Upon scanning the homes, a data conversion pipeline as shown in Figure 1 below was developed to allow for processing of the resultant large data sets to prepare them for visualization within the CAVE system. Furthermore, the team internally developed an initial visualization application for rendering the 20 homes in the CAVE system. No commercially

available solutions existed that could render these data sets in the CAVE virtual reality display system.

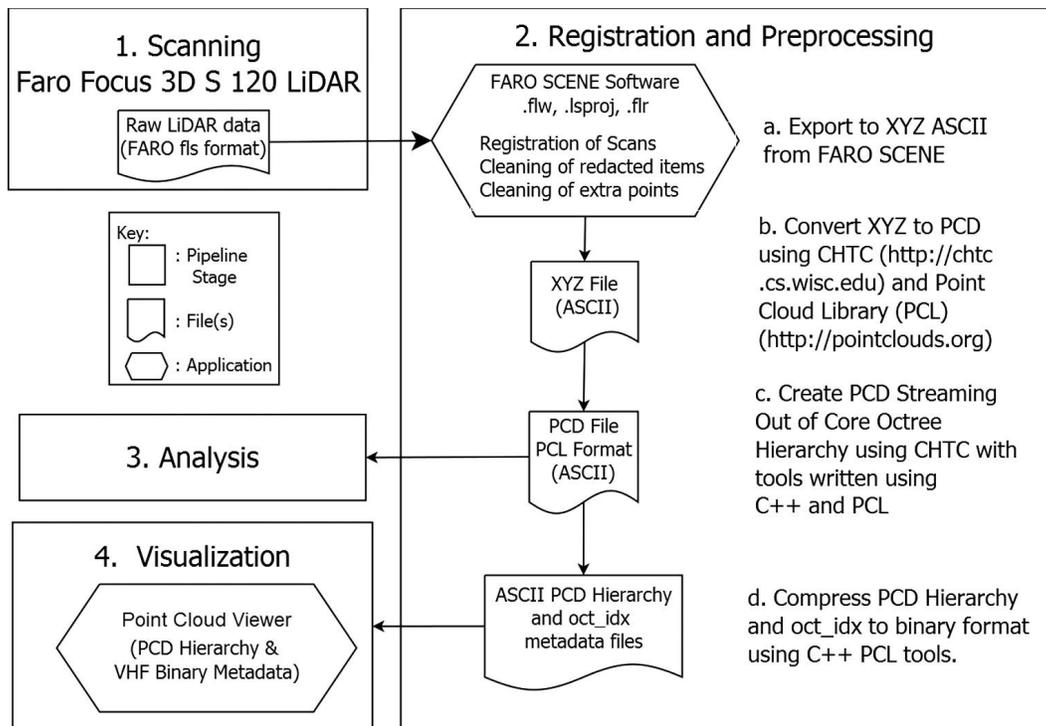


Figure 1: vizHOME Data Acquisition to Visualization Pipeline

Results

The mean age of participants was 59 (sd=12), 65% were white, 70% were females, and 25% lived alone. Using the Economic Hardship Index (EHI), we revealed that participants represented the spectrum of hardship from lowest (7), to middle (5), to highest (8) hardship. All participants had a cell phone, a landline or both; all but one household had a laptop or a personal computer. We identified over 100 different tasks, and explored 60 in depth (3 per participant).

Findings demonstrated that most people perform PHIM tasks in multiple areas of the home at varying times of day. This suggests a distributed nature of even apparently simple and similar tasks, such as taking medication or checking a blood sugar. The vignettes below illustrate the distribution of the location and timing of PHIM task performance within individuals and across households. By consolidating data from the interviews and the maps, we discovered that PHIM task steps occur throughout the day and the home. Most PHIM tasks occur in the kitchen, living room, and bedroom.

We analyzed a total of 60 tasks: 20 medication management tasks, self-monitoring tasks, and information management tasks. With only one exception, tasks related to medication management occurred not at a single point in time, but as a discrete set of steps unfolding over long intervals (95%) and in several different spaces in the home (90%). Similar variability in space and time was observed with general information management tasks (75-80%) and self-monitoring tasks (80-55%).

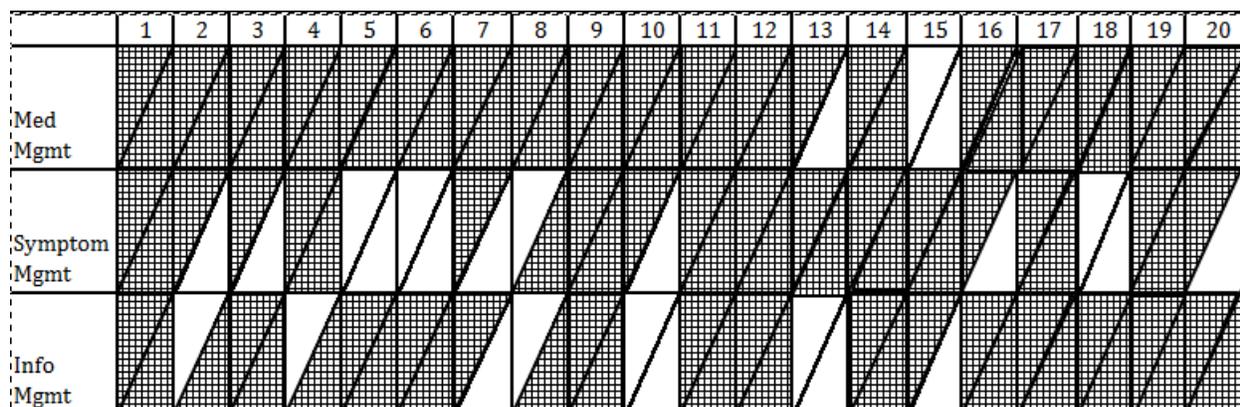
Figure 2: Sample Vignettes

Each day at 9:30am, Participant A retrieves her glucometer and log book from the dresser in the spare bedroom. She brings it to the kitchen table where she checks and records the reading. If she wants help interpreting the reading or advice on what to do, she goes to the telephone in the living room to call a friend who has diabetes. When done, she returns the glucometer to her bedroom. She repeats this procedure before her evening meal. She relies on memory and routine to perform these tasks.

Participant J has four to five appointments with different health care providers each week at varying times of the day. She uses both a travel planner and a main planner to record all her appointments. As she leaves an appointment she records upcoming appointments in the travel planner, which she stores in her backpack. When she returns home, she transfers the appointment information into her main planner which she keeps under her bedside table. She refers to this main planner on a daily basis.

Every morning before breakfast, Participant L counts out his morning and evening pills from their individual bottles that he stores on his bedroom dresser. He leaves his evening pills on the dresser and takes his morning pills with him to the kitchen where he obtains an aspirin from a cabinet; he then ingests all pills at the dining table. He has another pill that he takes with dinner; he keeps this medicine bottle on the dining table as a reminder to take it. Around 9pm, when his wife goes to bed, he retrieves his evening pills from the bedroom dresser and brings them to the kitchen counter. He takes them around 11pm. He primarily uses environmental cues and diurnal events to perform these tasks.

Figure 3: Distribution of PHIM Tasks Across Time (Top Triangle) and Space (Bottom Triangle) For the 20 Participants (Hatched Areas Represent Presence). A hatched upper triangle signifies that the task is performed across time at the same space in the home. A hatched lower triangle signifies that the task is performed at the same time each day, across multiple spaces within the home. A hatched upper and lower triangle means that the task is performed multiple times a day across multiple spaces of the home.



Subproject 2

Purpose

The purpose of SP2 was to enumerate a set of household features that six experts from the vizHOME team identified as either a facilitator or barrier to PHIM. This enumeration served as the basis for the experimental requirements validation efforts in subprojects 3 and 4. In addition, the protocol for home assessments was developed and tested; recommendations for refinement for use with lay participants were identified.

Scope

In this phase of the project, six members of the research team, designated as experts, performed walkthroughs of randomly assigned virtual homes in the CAVE. They tagged objects, spaces, and devices (later labeled as 'features') perceived as relevant to PHIM tasks.

Methods

Virtual Home Assessment Task and Training: A video was used to: orient the experts to the project; the home assessment task; the immersive VR environment; the stereoscopic 3-D glasses, the wand, and virtual tagging for use in the CAVE. To complete the home assessment in the virtual model of the home, experts were asked to identify key features that would be useful or not useful for the resident of the home based on their expert perspective. A second set of videos was used to orient experts with each of the homes they would assess and the PHIM tasks residents performed in each home. A brief outline of the resident's PHIM tasks and a map was provided for each house.

Protocol for Home Assessments: A detailed protocol was utilized to ensure consistency in the home assessment procedures by each of the experts. A research assistant served as a guide for each home assessment while another technical assistant ran the CAVE and solved any technical issues. Experts were allowed a maximum of 15 minutes to explore each home and tag items by selecting items using the wand. The experts tagged the items they believed would either facilitate or inhibit the resident's performance of PHIM tasks.

Methods for Data Collection: Virtual renderings of homes (16 of the 20 homes scanned in SP1) were viewed in the CAVE by the six research team members across two non-contiguous weeks. Homes were randomly assigned to experts; then purposeful adjustments to the assignments were made to accommodate schedule and avoid order and team effects (e.g. the same 3 experts viewing the same set of homes). Each home was viewed 3 times, and each expert viewed a total of 8 homes. Data from one expert in one home was discarded due to CAVE display issues, thus the total number of home assessments was 47.

The self-report survey included the 6-item investigator developed PHIM task experience, a modified NASA-TLX (a measure of task burden) (Hart and Staveland, 1988), and a 4-item subset of Kennedy et al.'s Simulator Sickness Questionnaire (Nausea, Dizziness, Eyestrain, Headache) (Kennedy et al., 1993) was collected using Qualtrics on an iPad. NASA data was collected once after viewing 3 homes and once after the fourth home in week 1. In week 2, however, NASA was collected four times i.e. once after every viewing. Number and location of tags, time in CAVE, and audio recordings of think-aloud while in the CAVE were documented on paper forms.

Capture of CAVE data included x, y, z coordinates of objects/spaces that were tagged; thus, we have the potential to re-create experts' paths through the homes, but have not yet done so.

Qualtrics data was exported to an Excel file at the end of each day; CAVE-collected tag data was stored on secure drives at the Wisconsin Institutes of Discovery.

Debriefing: A research team debriefing session was held at the end of each week during which all tags made in each home were displayed on the Dev Lab wall, one house at a time. For each house, each expert's tag was assigned a unique color and tag overlap was detected by the combination of the colors. The expert group reviewed all tags, identified unintentional or erroneous tags, and discussed reason(s) for tagging an object. The only barrier to PHIM task performance identified was the presence of household clutter, which was not unanimously agreed upon. Due to scheduling constraints, we were only able to ensure that all experts who actually were in the virtual home were present during its debriefing.

Technical Developments: For subproject 2, the previously developed visualization software for the CAVE application was built upon to add a feature for highlighting objects, spaces, and areas within the homes. This involved treating the 3D input device used within the CAVE as a "virtual highlighter", where persons could mark areas with a bright yellow color, by pressing a button on the wand. This feature was essential for Subproject 2 as it allowed tagging of features within the homes, which were later reviewed and used to begin a list of commonly tagged objects amongst subproject 2 participants. The visualization software was developed with the capability to load

previously tagged object highlights, and also overlay multiple highlights on top of each other to find common areas of interest. To aid in navigation of the homes, such as moving up and down stairs, a collision detection system was added to the visualization software. This feature eased the ability to navigate throughout an entire home within the CAVE, by only requiring the user to navigate by using the joystick on the 3D tracked input device.

Results:

Requirements definition: Overall, 68 unique objects were tagged and a grid displaying objects by house by room was created for each of the two home assessment sessions. To gain a better understanding of the data, multiple approaches to its visualization were undertaken (e.g. frequency of objects by room, by type of house, by week of assessment). A paired object by room display of the 68 items is included in this report.

Figure: Enumerated List of Features Identified in SP2

Backpack	Free weights	Shelves
Bag	Inhaler	Slide holder
Basket	Keyboard	Smart phone
Bookshelf	Laptop	Sofa/couch
Cabinets	Letter holder	Steps
Cabinet, file	Light switch	Storage bin or box
Calendar	Magazine rack	Stove
Cane	Magazines, books, publications,	Table, coffee
Chair	documents	Table, desk
Clock	Mirror	Table, dining
Clock radio	Nightstand	Table, end (vanity)
Closet, inside	Picture frame	Table, library
Closet, top	Pill bottles	Tablet
Coffee maker	Pill organizer	Telephone
Commode	Printer	Toilet
Computer	Purse	Toilet tank, top
Counter	Radio	TV & remote
CPAP	Refrigerator, artifacts	TV tray
Door	Refrigerator, med storage	Walker
Drawers	Refrigerator, top	Wall above sink
Dresser/bureau, drawers	Reminder cards	Waste basket
Dresser/bureau, top	Scale	Water dispenser
Floor	Scooter	Whiteboard

Tag Data Analysis: A master grid was created for each of the two weeks that display tagged features by room in each house. The feature list was derived from tagged objects in the CAVE by all the experts. Conclusions from exploratory analysis include: 1) number of tags was not related to the type or size of the house, number of its floors, or the clutter rating, 2) the number of tags generated by each individual varied across houses, but did not appear to be influenced by individual characteristics, 3) there tended to be more tags in week 2 than in week 1, which may have been influenced by the group debriefing process, 4) the spaces with the most tags were kitchen, master bedroom, living room, and master bathroom in no particular order.

Survey Data Analysis: Because the NASA-TLX is reported as a total score, we pursued that approach to analysis for each individual in each house. Participants tended to demonstrate a consistent response pattern over the two weeks, with half trending to higher scores and half trending to lower scores. While the individual NASA-TLX scores appear to be independent, a response pattern emerged that persisted throughout suggesting that NASA-TLX response is characteristic of the individual.

Simulation Sickness Items responses were primarily in the none-mild range, roughly 10-15% were in the moderate response category. There were no reports of severe symptoms on any of the items at any of the measurement times. In comparison to the NASA-TLX score, the SSQ item responses were more stable within individuals across both weeks. Additional exploratory analyses were conducted to look for relationships within and across individuals with no strong correlations detected among responses.

Qualitative Data: Technical issues encountered during the CAVE walkthroughs were documented on the guide notes and transcribed in a Word document. Of the 48 walkthroughs, 14 issues were recorded in week 1 and only 7 issues occurred in week 2. The cause of several technical difficulties was resolved between week 1 and 2 e.g. changes in code reduced the possibility of navigating through the ceiling.

It was decided that next steps in feature analysis would involve mapping between objects, standard terminologies, and a thesaurus as well as developing consensus around the affordances of objects on the list. Additionally, we manually and visually explored the impact of proximity on feature selection. We were unable to automate the proximity analysis due to the fact that it was not sensitive to the presence of walls or other spaces between two features.

Subproject 3

Purpose

The purpose of Subproject 3 (SP3) was to enumerate a set of household features that lay participants who reported being told they had diabetes identified as facilitating or barring their PHIM. This was compared to the list generated by the experts in SP2. The results of this comparison or combined list served as the basis for the requirements refinement and validation efforts in SP4.

Scope

In this phase of the project, 20 community-dwelling lay participants who had been told they have diabetes (same eligibility criteria as SP1) viewed two randomly assigned homes each in the virtual reality CAVE.

Methods

In this exploratory study, participants navigated inside of two homes in the VR CAVE and were asked to tag features within each of the homes that would support or serve as a barrier to PHIM. Similar to SP2, a detailed protocol and script were utilized to ensure consistency in the presentation and guidance through the home assessment procedures. An undergraduate research assistant served as a guide for each home assessment while another technical assistant ran the CAVE and addressed any technical issues that arose. Participants were allowed a maximum of 15 minutes to navigate through each home and tag all features that would affect their PHIM. They also had an option to tag a space where a feature *they would use* was missing (e.g. a participant might tag a wall where they would have a calendar or tag the bathroom floor where they would have a scale). After each home assessment one on one debriefing sessions were conducted by a doctorally prepared research team member with the participant. The sessions reviewed each of the tags, confirmed the participant's intent, and documented the location and any explanatory notes about each selection. Following the debriefing participants completed a survey, were offered a snack, and the opportunity to rest before viewing the next home. Survey data was collected using Qualtrics on a dedicated tablet. The collected data included: demographic data; a 6-item investigator-developed PHIM task experience; modified NASA-TLX, and a four item (nausea, dizziness, eyestrain, headache)

simulator sickness questionnaire (SSQ). NASA-TLX data was collected just once after the participant completed viewing both homes. The number and location of tags, time in CAVE, and debriefing notes were documented electronically. Audio recordings were captured of some orientation sessions, all of the participant's "think-aloud" utterances while in the CAVE, and most of the debriefing sessions. Capture of CAVE data included the x, y, z coordinates of objects/spaces that were tagged; thus, we can recreate participants' paths through each home, but have not yet done so.

Technical Developments

Further refinement of the visualization software took place during subproject 3 focusing on quality of the rendered image and improved interactive frame rates.

Results

The 20 participants had a mean age of 54 years (sd 14) with an age range of 22 to 75 years (age was missing for one participant). Ten participants were male, nine female and one participant self-identified as genderqueer. The majority of participants (18) were white, one identified as black, and one identified as Asian; there were no Hispanic or Latino participants. Typical of the area in which this CAVE study was conducted, educational level was skewed to the higher end with four participants reporting a graduate degree, ten earned a college degree, and six graduated high school. Participants' rating of their health on a global rating scale were fair (4), good (9), very good (6) and excellent (1). The majority of participants had no prior CAVE or Virtual Reality experience.

Survey Data: The four SSQ items were administered as a baseline measure and after each house viewed. Across all measures of the SSQ items, the majority of participants indicated "none" (0) in response to the severity of the four items; a few chose mild for a single symptom; and none rose to the level of the moderate or severe response categories. There were no reports of severe symptoms on any of the items at any of the times it was measured. The NASA-TLX scores for its six items were dispersed across the theoretical range and lacked consistency or pattern that would support meaningful interpretation of the individual subscale or summative scores.

Tag Data: Tag data was exported into R statistical package and several approaches to visualization of the data were implemented (e.g. frequency of objects by room, identification of new features tagged by participant, and identification of other (new tags) and tags of missing items as previously defined.) These lay participants tagged 52 unique features (compared to the 70 features tagged by the research team members in SP2). Twenty-one features tagged in SP2 were not tagged in SP3; while 3 features were tagged in SP3 that were not tagged in SP2. A key finding was the comparability of professional and lay identification of features for PHIM, lay people identified similar features, but tended to identify fewer features per home. The final merged enumerated list served as the basis for planning Subproject 4.

Subproject 4

Purpose

The purpose of Subproject 4 (SP4) was to reveal an enumeration of a set of household features that lay participants identified as most useful for PHIM. By manipulating the variables (features) that previous subprojects had determined to be useful in managing PHIM, SP4 efforts enabled the refinement of the feature list by observing participants' sensitivity to them. Hence, this enumeration served as a prioritized version of the original lists generated by the research team

in SP2 and the lay participants in SP3. In combination with findings from SP2 and SP3, the SP4 enumeration informed the development of the survey, the Assessment of the Context of the Home Environment (ACHE), that will be developed and utilized in SP5. We envision that the ACHE will be useful for device designers, architects, and health care providers for discharge planning. The purpose for developing and using this instrument (the ACHE) in SP5 is to document the location and presence of the key features in homes across the state and to enable appraisal of the generalizability of homes captured in SP1.

Scope

The target for recruitment for this phase of the project was 60 community-dwelling lay participants who had been told they have diabetes (same eligibility criteria as SP1 and SP3). In order to more narrowly focus on the specific features, participants viewed three randomly assigned sets of five rooms and identified the two most useful features in each room in the CAVE. Rooms were purposefully selected because they contained most, if not all of the features of interest.

Methods

Participant Training: Investigator developed PowerPoint slides with a script-driven audio component were used to: orient the participants to the vizHOME project; the home assessment task; the stereoscopic 3-D glasses, the wand and tagging and to the immersive VR environment, the CAVE. Similar to previous subprojects, a detailed protocol and script were used to guide participants through the home assessment procedures.

Design of the Virtual Experience: Features that had been identified as priorities in previous SPs were segmented or boxed for visualization and thus were able to be selected. Examples of such features include: cabinets, bookshelves, nightstands, tables, and computers. Room selection was based on the presence of these segmented features in them. Tasks were designed and used to ensure that all participants would respond to the same demands for PHIM; and those who experienced the same set of room sequences would be responding to identical stimuli. The three standard PHIM tasks were crafted to address common PHIM issues for people living with diabetes: seeking information about a potential side effect of a medication, checking and recording daily blood sugar readings, and maintaining health care appointments.

Data Collection: In the task-based home assessments developed for this Subproject, participants were teleported through a series of five non-contiguous rooms and identified the most useful and second most useful tagged features for the assigned tasks in each room. In contrast to previous subprojects in which any feature or space in any room could be tagged, in SP4 options were limited to the generated list from SP3. Per protocol, a research specialist served as a guide for each home assessment while another technical assistant ran the CAVE, solved technical issues and recorded time in the CAVE.

Survey Data: The self-report survey included: demographic data; a 6-item investigator-developed PHIM task experience; modified NASA-TLX, and 4 SSQ items (Nausea, Dizziness, Eyestrain, Headache) and was collected using Qualtrics on a desktop computer adjacent to the CAVE. NASA-TLX data was collected just once after the participant completed all three tasks. Participants completed the subset of SSQ items at the completion of each of the three home assessment tasks and were offered a snack and break before moving to the next task. Number and location of tags, time in CAVE, and debriefing notes were documented electronically by a member of the research team. Audio recordings were captured of some orientation sessions and all of the participant's "think-aloud" while in the CAVE. Capture of CAVE data included x, y, z coordinates of objects/spaces that were tagged.

Technical Developments

The main technical developments during subproject 4 involved enhancements to the visualization software to allow users to teleport between different rooms in different houses during the same visualization session of a participant within the CAVE. Along with this, the ability to load bounding boxes around objects and make them selectable within the CAVE visualization software was added and became crucial to the subproject. The ability to select boxes gave users the ability to choose which objects were most relevant to the given task description across a variety of room and home types. Both of these features drove the design of the testing protocol for this subproject, which in turn allowed for further refinement of the list of objects towards the creation of the ACHE. In order to analyze the results more efficiently a tool was developed that rapidly sorted, filtered, and combined results together. This tool enabled the user defined concatenation of terms, such as “table” and “coffee table” allowing for rapid analysis. The tool also provide a means of controlling the layout of results, enabling users to quickly visualize a number of different possible sortings, such as item vs room, item vs task, etc. The final results were exported into traditional statistical software.

Results

The 60 participants had a mean age of 58 years (sd 16) with an age range of 20 to 86 years; 53% of the participants were male. The majority of participants (46) were white, nine identified as black, two identified as Asian, and three selected “more than one race.” There were two Hispanic or Latino participants. Typical of the area in which this CAVE study was conducted, educational level was skewed to the higher end with 18 reporting a graduate degree, 23 earned a college degree, 18 graduated high school, and one had “some high school”. No participant lived in a mobile home. The majority of participants had no prior CAVE or Virtual Reality experience.

As was observed in previous subprojects, the NASA-TLX scores for the six items were dispersed across the theoretical range and lacked consistency that could justify reporting total scores. Across all measures of the SSQ items, the majority of participants indicated “none” (0) in response to the severity of the four Simulation Sickness items; many chose “slight” for a single symptom; and a few rose to the level of the moderate for a single symptom as well. There were no reports of severe symptoms on any of the items at any of the measurement times. In comparison to the NASA-TLX test, the SSQ item responses were considerably more stable within individuals in all homes and across individuals regardless of home.

Analysis of the frequency and location of tags enabled identification of features to be included in the ACHE. In-depth analysis of the tag data, including appraisal of ambiguities, proximities, and affordances, did not reveal significant common, possibly explanatory, characteristics of the features. In general, the three most useful tools were: computer, nightstand, and end table.

Desks and dining tables were also frequently selected. When assessed by task, cabinets and end tables were most useful for investigating information about a particular medication.

Calendars, computers, and nightstands were the most useful features for maintaining health care appointments. Nightstands, dining tables, and end tables were most useful for monitoring and recording blood sugar values. It is important to note that substantial variation across individuals was observed. Participants also had the opportunity to tell the guide that they were looking for an item that was not present in the room. Although this was not a frequent occurrence, there were three features that were sought more often than others: calendars, computers, and phones. While these were present in each sequence of rooms, they were not always found in the room where the participant expected them to be.

Subproject 5

Purpose

Subproject 5 builds on the knowledge gained in previous subprojects (SP2, 3, and 4) about features that impact performance of Personal Health Information Management (PHIM) tasks in the home. The purposes of SP5 were 1) to provide evidence for the generalizability of our findings which are based on the 20 homes captured in SP1 and 2) to document the presence and location of the 10 most useful features (determined in the findings of SP 2 through SP4) in 200 homes across the state of Wisconsin. Questions for this research addressed the extent to which: the features identified through Subprojects 1-4; were generalizable to a larger array of households and were present in specific rooms; household characteristics were similar to those found in SP1; and comparability of demographic characteristics of residents in the homes.

Scope

The target for recruitment for this phase of the project was 200 homes across the state whose residents were participants in the Survey of the State of Wisconsin (SHOW). Unlike previous subprojects, we did not specifically seek people who had been told they have diabetes or any other chronic illness. Key to our ability to establish a generalizability across the state of Wisconsin was our partnership with the Survey of the Health of Wisconsin (SHOW). SHOW is a well-established, longitudinal, community based survey research project which sought participants who would be representative of citizens of the state. SHOW conducts household surveys of community-dwelling residents including collecting data about such aspects of health as: personal health characteristics, family structure, access to health care and neighborhood features. Our partnership with them not only provided the vizHOME team with access to a community sample but also afforded a reference population against which we could compare our findings and estimate the generalizability of our results. In order to focus on the homes themselves, SHOW field staff were trained to look for and document the presence of the ACHE features in the homes of their participants.

Methods

The ACHE, designed by the research team, consisting of the 10 most commonly identified features identified in earlier subprojects was used to document the presence of these useful features in the wider array of households surveyed in SP5 (see ACHE below).

Training: vizHOME staff conducted training sessions for SHOW's field staff on the background of the study and information required to accurately and efficiently complete the ACHE in all homes interviewed. Training took place in the VR CAVE. It included a series of Powerpoint presentations developed by the project director aimed at transmission of knowledge, and opportunities to practice ACHE completion in two virtual homes. These Powerpoint files, with complete notes, were provided electronically to all field staff after completion of in-person training. Subsequently, SHOW field staff completed an ACHE in a supervisor's home under the guidance of a field manager. The vizHOME project director participated in a series of weekly calls with field staff to discuss progress and address any questions that the SHOW interviewers experienced with using the ACHE in the field.

Protocol for Home Assessments: Administration of the ACHE by SHOW field staff took place over a 6-month period. SHOW field staff in five Wisconsin counties across the state, visited participants' homes and completed the ACHE form. SHOW staff administered the inventory as part of the battery of in-house assessments completed for the routine SHOW assessment.

Sample: The target sample for SP5 was 200 homes, but the final sample included completed ACHEs for 247 homes. A larger sample of homes was obtained because SHOW continued collecting data after reaching the target while awaiting IRB approval to stop data collection. A total of 322 residents in these homes completed the SHOW core data questionnaire. SHOW

electronically delivered scans of completed ACHEs in batches to vizHOME and transferred the core data set to vizHOME approximately nine months after completion of the field study.

Reproduction of the Assessment of the Context of the Home Environment (ACHE)

<u>ACHE Feature</u>	<u>Living Room</u>	<u>Kitchen</u>	<u>Master Bedroom</u>	<u>Other Bedrms</u>	<u>Master Bath</u>	<u>Other Baths</u>	<u>Den/ Office</u>	<u>Dining Rm/Area</u>
<u>Cabinet</u>								
- upper (built-in)								
- lower (built-in)								
- free-standing								
<u>Calendar</u>								
<u>Computer/ Telecomm Device</u>								
- PC								
- laptop/ tablet								
- cell/smartphone								
- landline phone								
<u>Countertop</u> 8.5x11" usable work space								
<u>Drawers</u>								
<u>Nightstand</u>								
- w/ drawer(s)								
- no drawer(s)								
<u>Refrigerator Artifacts</u>								
<u>Storage Container</u>								
<u>Table</u>								
- w/ chair(s) to sit at								
- no chairs								

Technical Developments

The main technical development for subproject 5 was an analyzer tool that enabled us to quickly analyze large amounts of data from subproject 4. This facilitated revision of the list of objects for

the ACHE. This tool was developed in C++ using Qt, and gave the research team a viewable front end of the data all in one place. The tool also generated a color coded in a heat-map of the objects that were frequently chosen by participants in subproject 4.

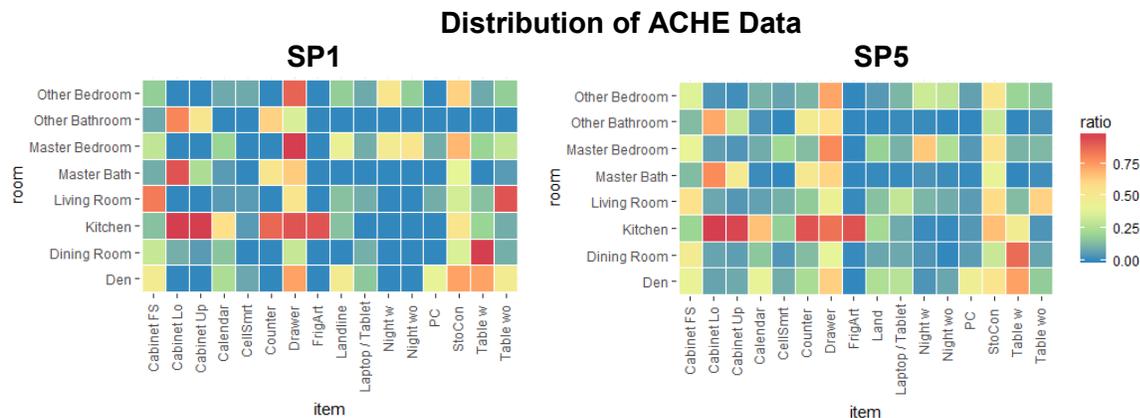
Results

Participants The 322 participants who responded to the SHOW survey had a mean age of 56 years (sd: 14) with an age range of 25 to 82 years with 37% of participants male. The majority of participants (88%) were white, five identified as Hispanic or Latino. As in previous SPs, educational level was skewed to the higher end with 13% reporting a graduate degree, 51% earned a college degree, 23% graduated high school, only 6% had less than a high school diploma. Income range was wide, with 9% reporting annual household incomes less than \$20K, 30% \$20-50K, and 7% greater than \$150K. Again, the economic hardship index demonstrated distribution across a wide range with 24% having the most hardship and 32% having the least hardship. In contrast to previous SPs, only 45% of the homes had a resident with a chronic illness. Participants' rating of their health on a global rating scale were: very poor (3%), poor (9%), fair (38%), good (40%) and excellent (10%), thus using the entire range of the scale.

The first figure below illustrates the presence and distribution of the ten features across the homes surveyed in SP5. It is important to note that the ACHE documented the presence of the features, not their use. Proportions are used to reflect the actual number of features observed in relation to the possibility for it to be observed e.g. a feature could not be observed in a den if the home did not have a den - it is corrected for the presence of a room in a home. This data also aided in evaluating the accuracy of the ACHE data e.g., note that the feature refrigerator artifact ('FrigArt') is found only in the kitchen, as one would expect almost all refrigerators to be located in a kitchen; similarly nightstands are found almost exclusively in the bedrooms.

Distribution of ACHE Data for SP5

Collecting the ACHE data in SP5 enabled the important comparison of the presence and location of features in SP1. To make this comparison, we engaged a student not familiar with the vizHOME project to complete the ACHE on the 20 virtual homes captured in SP1 in our virtual reality CAVE. The student received the same training as SHOW field staff and was allowed a maximum of 15 minutes to navigate each home. A research team member familiar with the virtual homes was present to answer any questions that a SHOW field staff may have asked of an actual home resident, e.g., confirming room type, or the presence or absence of a specific room in the home. The heatmap of this data is illustrated in the image below.



The observed presence and location of most of the features appears similar between the 247 actual homes and the 20 virtual homes. Thus, the goal of capturing a representative sample of homes in SP1 was supported. An important consideration in interpreting the presence of some features is warranted and is related to the visibility of the specific feature - e.g. cell phones, laptops or glucometers may have been present, but not visible due to their mobility or storage preventing viewing.

Conclusions

This project aimed to illustrate which features of the home context shape PHIM and the extent to which task factors and personal characteristics alter the influence of the household context on PHIM. Overall we found medication management is very decentralized and locations for performing common tasks varied greatly depending on the affordances in the homes. For example, the considerations for storing medications included the integrity of the medication, safety, accessibility, and visibility. The storage of information and policies guiding medication storage varied greatly across homes and different individuals living there within. Furthermore, while individuals may have medical devices in the home, it was not clear that these devices were being used as intended. However, in summary, it was found that individuals tended to adapt PHIM to the environment around them more than adapting the environment to accommodate the task. From TV shows serving as cues to take a medication, or the color-coding on a kitchen calendar to signify types and timing of appointments, to having a refrigerator in the bedroom to enable taking medication after retiring - the individualization of routines customized to the home, even specific areas within the home, was apparent. This finding underscores the importance of design informed by understanding how and where patients actually perform tasks in their homes – not how they tell us they would perform them or even how they show us when in a hospital or clinic. Given this finding, it is critical for health care providers to understand the environment in which an individual will be performing PHIM and to tailor PHIM recommendations to the environment.

Dissemination

The final goal of the vizHOME project was to make our data and findings accessible to our target audience including device designers, computer scientists, and healthcare providers. Dissemination of the models and supporting materials involved exploration of feasible alternatives that maximize accessibility of the products of this work (e.g. point cloud data, reconstructed home models, characteristics of the homes, etc.). We identified the following elements and characteristics as important considerations in developing our approach to model dissemination that would be both reasonable and feasible: method(s) of display; non-proprietary open source data format with documentation (e.g. XYZ file format); and identification of the metadata to include such as type, clutter rating, and size of house. The Wisconsin Institute for Discovery hosts the website. The infrastructure for the dissemination will enable users to better understand the data before download. So, in addition to publication of findings through conferences and journals, we developed a website (<http://pages.discovery.wisc.edu/vizhome/>) containing key data and findings of the project.

Broader Impacts of the Project

The techniques developed for use in vizHOME and the insights that the project generated have created a new standard in regards to what objects within the home environment impact a person's ability to perform PHIM. The project has also provided insight as to which of these objects currently exist across a sample of actual homes in the state of Wisconsin. It is through this project that designers, researchers, medical professionals, and other applicable parties now have a resource and tool (the ACHE) for reference when assessing home environments for

PHIM. Additionally, the project has invigorated further work in the field of healthcare and beyond. Projects that have resulted from this work include:

Including Homes in Health Records

<https://healthit.ahrq.gov/events/national-web-conference-use-health-it-aging-adults>

As the team saw the benefits of the virtualization of home environments, a project was undertaken to explore how these datasets could be included in the electronic health record. The AHRQ R03 project HS024623 Virtualized Homes: Tools for Better Discharge Planning, created a partnership between the University of Wisconsin Hospitals and Clinics and Epic Systems. This project, alongside the vizHOME project, was presented as part of a National Web Conference on the Use of Health IT for Aging Adults for AHRQ in July of 2017.

Study of Homes for Crime Scene Investigation

<https://3d-csi.discovery.wisc.edu/>

As the team was scanning homes for the purposes of studying health, an unexpected collaboration emerged. After a homicide occurred in a nearby town, the team was contacted by the local sheriff's office and the FBI to perform the same methodology developed in this project for the purposes of CSI. This collaboration was considered an overwhelming success and the team applied for funding opportunities to explore furthering the collaboration. In early 2017, the team was awarded the project funded by the Department of Justice, 2016-IJ-CX-0017 Analyzing the Impact of Virtual Reality and 3D Capture Technology on Crime Scene Investigation.

Cultural Heritage

The project team has also found applications in the areas of cultural heritage. The team first teamed with Taliesin Preservation Inc. and the Frank Lloyd Wright Foundation in 2014. The team scanned approximately one-third of the 40,000-square-foot estate capturing locations that are not available on regularly scheduled tours of the estate due to accessibility limitations. The model created from those scans contained nearly 2 billion points in a single binary data file almost 35 GB in size. The data set is the largest and most detailed 3D model of Taliesin East in existence.

Members from the vizHOME team have also partnered with the National Parks Service in capturing accurate 3D models of underwater shipwrecks. Underwater video and images were taken of several shipwrecks located near the Isle Royale National Park in Michigan. Members from the vizHOME team use photogrammetry techniques on these videos to reconstruct 3D models. In addition to the Isle Royale, recently a member of the team went to Dry Tortugas National Park in Florida to continue working with the National Park Service on reconstructing 3D models of shipwrecks in that geographic region. The group's work in the area of cultural heritage was recognized on the cover of the [National Historic Preservation's Forum Journal](#).

New Intellectual Property

The project team quickly found that existing methods to render point clouds in virtual reality were insufficient for the project. A new rendering system was created which enabled both a high level of interactivity while maintaining high quality visuals. This work was patented by the Wisconsin Alumni Research Foundation and in 2018 funding was given to broaden the impact of this work.

Final Report References

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology* (Vol. 52, pp. 139-183). North-Holland.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, 3(3), 203-220.

Moen, A., & Brennan, P. F. (2005). Health@ Home: the work of health information management in the household (HIMH): implications for consumer health informatics (CHI) innovations. *Journal of the American Medical Informatics Association*, 12(6), 648-656.

Publications and Products

Brennan PF, Ponto K, Casper G, et al. Virtualizing living and working spaces: Proof of concept for a biomedical space-replication methodology. *Journal of Biomedical Informatics* 2015; 57: 53-61. PMID: 26173040.

Broecker M, Ponto K, Tredinnick R, et al. SafeHOME: Promoting safe transitions to the home. *Studies in Health Technology and Informatics* 2016; 220: 51-54. PMID: 27046553.

Casper GR, Brennan PF, Perreault JO, et al. vizHOME – A context-based home assessment: Preliminary implications for informatics. *Studies in Health Technology and Informatics* 2015; 216: 842-846. PMID: 26262170.

Casper GR, Brennan PF, Smith CA, et al. Health@ Home moves all about the house!. *Studies in health technology and informatics* 2016; 225, 173-177. PMID: 27332185.

Casper GR, Jarzemsky PA, Athanas JD. Extending informatics education to home care. *American Medical Informatics Association (AMIA) Annual Symposium*, November 2016.

Hoonakker PLT., Casper G, Peer A, et al. Healthcare in a virtual environment: workload and simulation sickness in a 3D CAVE. *Proceedings of the 20th Congress of the International Ergonomics Association*; 2018 Aug 26-30; Florence, Italy. Cham (Switzerland): Springer Publishing; 2018:281-289

Jolliff AF, Hoonakker P, Ponto K, et al. The Desktop, or the Top of the Desk? The relative usefulness of household features for personal health information management. Revisions submitted to Elsevier Editorial System for *Applied Ergonomics*, 82, 102912..

Ponto K, Brockberg D. vizHOME: Using LiDAR to create point cloud representations of home interiors. *The 22nd Medicine Meets Virtual Reality (MMVR) Conference*; 2016 April 7-9 ; Los Angeles, CA.

Ponto K, Tredinnick R, Casper G. Simulating the experience of home environments. *2017 International Conference on Virtual Rehabilitation (ICVR)*; 2017 June 19-22; Montreal, QC. Piscataway (NJ): IEEE, 2017:1-9.

Smith, C.A., He, Y., Casper, G. (2017). Mapping the virtual home: A new taxonomy for an expanded perspective. Podium presentation, *AMIA 2017 Annual Symposium*.

Smith, C.A., Tredinnick, R., Casper, C., Ponto, K. (2017). Virtualizing Homes to Study Health Decisions. http://wish.gatech.edu/wp-content/uploads/smith_catherine.pdf

Subramaniam NA, Ponto K. Hierarchical Plane Extraction (HPE): An Efficient Method For Extraction Of Planes From Large Pointcloud Datasets. *Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture*; 2014 Oct 23-25; Los Angeles, CA. Los Angeles (CA): Riverside Architectural Press; 2014:627–36.

Tong M, Borkenhagen A, Casper G, et al. Exploring interactions in the home environment: Personal health information management strategies of patients with chronic illness. *Proceedings of the 2017 International Symposium on Human Factors and Ergonomics in Health Care*, 2017 March 5-8; New Orleans, LA. Washington DC: Human Factors & Ergonomics Society; 2017.

Tredinnick R, Broecker M, Ponto K. Experiencing interior environments: New approaches for the immersive display of large-scale point cloud data. In Höllerer T, Interrante V, Lécuyer A, et al, ed. *Proceedings of the 2015 IEEE Virtual Reality Conference (VR)*; 2015 March 23-27; Arles, France. Piscataway (NJ): IEEE, 2015:297-98.

Tredinnick R, Broecker M, Ponto K. Progressive feedback point cloud rendering for virtual reality display. In Höllerer T, Interrante V, Lécuyer A, et al, ed. Proceedings of the 2016 IEEE Virtual Reality Conference (VR); 2016 March 19-23; Greenville, SC. Piscataway (NJ): IEEE, 2016:301-302..

Werner NE, Carayon P, Casper GR, et al. Affordances of household features important to personal health information management: Designing consumer health information technology for the home. In Mollo V, Falzon P, Ed. Proceedings of the Healthcare Systems Ergonomics and Patient Safety Conference; 2016 October 5-7; Toulouse, France. Thônex, Switzerland: International Ergonomics Association, 2016:390-394.

Werner NE, Jolliff AF, Casper G, et al. Home is where the head is: A distributed cognition account of personal health information management in the home among those with chronic illness. *Ergonomics* 2018, 61(8), 1065-1078.