# Virtualizing Homes to Study Health Decisions

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**Abstract**

Consumer health information technologies would benefit from a clearer understanding of the unique personal health information management (PHIM) practices of chronically ill people. There is growing evidence that context shapes health information management behaviors, but awareness of the places within which people conduct specific health-related tasks is lacking[2]. We posit that better understanding of the home context could lead to improved design of information technologies tailored to the needs and context for home use[3]. We report here on the current status of a project that focuses on the visualization of homes and the use of virtual models, as an illustration of how researchers can work with citizen participants to collect novel and personal data. The 5-phase vizHOME project (AHRQ R01HS022548), is designed to systematically determine how household context shapes PHIM in the home through in-depth explorations of 1) PHIM strategies employed by people who report having diabetes and 2) the context of their homes. The five subprojects of vizHOME have used virtual reality technologies (LiDAR, the CAVE) for data collection by lay participants, requiring visualization and naming of 3D data to generate a new instrument for more data collection. The more we engage with the data of the home, the more data teaches us about the home and the more customized technological solutions can be to the person who lives there.[8]

**Introduction**

Consumer health information technologies would benefit from a clearer understanding of the unique personal health information management (PHIM) practices of chronically ill people. There is growing evidence that context shapes health information management behaviors, and attention to the process of decisionmaking (e.g., [1]) but awareness of the specific *tools* and *places* within which people conduct specific health- related tasks—as opposed to the location, is lacking[1]. We posit that better understanding of the home context, as facilitator or barrier to PHIM, could lead to improved design of information technologies tailored to the needs and context for home use[3].

The 5-phase vizHOME project (AHRQ R01HS022548), is designed to systematically determine how household context shapes PHIM in the home through in-depth explorations of 1) PHIM strategies employed by people who report having diabetes and 2) the context of their homes. We report here on the current status of the project, with a focus on the visualization of the homes and the use of virtual models, as an illustration of how researchers can work with citizen participants to collect novel and personal data.

Key to the vizHOME project is the Living Environments Lab (LEL) at the University of Wisconsin-Madison [https://wid.wisc.edu/research/lel/]. The LEL facilitates exploration of how technology shapes health, and aims to create technologies that better fit their demands and use, in everyday living. Faculty and students engage in projects with multidisciplinary teams beyond the health domain; collaborators stem from departments including Industrial and Systems Engineering, Design Studies, Library and Information Studies, Nursing, Art, and Dance. The common theme across these projects is the integration of 3D design, visualization and virtual reality environments into research, creative expression and education.

The LEL's primary instrument for research is a six-sided virtual reality (VR) CAVE. As VR continues to evolve the lab has adopted multiple additional visualization methods: head mounted devices (HMDs) including the Oculus Rift CV1, HTC Vive, and the Hololens; and a multitouch table used to gather data from the public. The LEL also has created two satellite visualization labs – the HMD-based Advanced Visualization Space in the School of Nursing and the DSCVR system, consisting of 20 47-inch TV monitors, in the School of Human Ecology.

**vizHOME Research Plan**

The goal of the vizHOME project is to better understand the impact of home environments on how chronically ill people perform PHIM tasks[4]. PHIM is defined for vizHOME as a suite of cognitive and behavioral tasks that people undertake to accomplish their health goals. These goals include monitoring health states, recording symptoms, communicating with clinicians, and making sense of discharge summaries, health-related web sites and clinician-provided handouts. PHIM may also include development of self-cues and systems to aid in remembering appointments or medication schedules[5, 6]. The vizHOME project is organized into 5 distinct subprojects, described below.

Subproject 1: LiDAR for data collection; the home as data

In this first phase, we conducted 1) in-depth interviews and 2) 3D image capture of 20 homes of resident informants managing a chronic illness (diabetes). The aims of the semi-structured interviews were to explore participants' PHIM strategies and to contextualize these strategies within the home. Capture of the physical environments were accomplished using an advanced data acquisition tool called a Light Detection and Ranging, or LiDAR, scanner to capture images of the entire interior of the homes. The terrestrial LiDAR scanner operates on a tripod, in contrast to aerial LiDAR scanners that are often attached to the bottom of aircrafts. The scanner rotates on the tripod and, using lasers and rotating mirrors, captures millions of 3D colored positions, called a point-cloud, of the environment surrounding its location of operation. A 12-minute scan can capture forty- five million points of data. A typical point-cloud for the vizHOME project represents 500,000 million to 1 billion points. To scan all areas of an environment, the LiDAR scanner is moved to successive adjacent locations and the process repeated until complete. (For details, see [7, 8, 9]).

A virtual model of the home is created through a process called registration, often with the aid of a software application provided with the LiDAR scanner. The vizHOME team developed a processing pipeline for optimizing the acquired data, using a lab-developed visualization application to view the 3D models across a variety of VR display devices, from the six-sided immersive walk-in CAVE to head-mounted displays[4, 7, 8, 9]. The result is a realistic, life-size, to-scale model of the home.

VR visualization of such models allows a user to feel as if they are physically located in the home environment. Since the model is 3D, and not a 360-degree photograph, users can virtually navigate anywhere they want throughout the home, using an input device such as a game controller. This combination of technologies allows us to study elements of PHIM in real home environments in a novel, efficient, and less intrusive manner.

These homes had not been modified to accommodate any chronic illness or disability; participants were asked not to change or "prepare" their homes for scanning visits. Thus, these scans generated a reference set of 20 virtual, but very real, 3D households while retaining their innate, personal ambiance and varying levels of clutter. In-depth interviews with home occupants resulted in a catalog of personal health information management (PHIM) tasks performed in each of the 20 houses. These tasks centered on medication management, self-monitoring, and general information management.

This reference set of virtual homes enabled the research team ("experts") and lay participants to perform home assessments in the Living Environments Lab's VR CAVE. In the ensuing subprojects two through four, described below, expert and lay participants alike navigated the virtual homes to identify features--household objects and spaces--that could impact PHIM done by the occupant. The focus of the whole project is on the environment in which tasks are performed, with diabetes being an exemplar of chronic illness for which PHIM is required.

Subproject 2: VR CAVE for data collection and visual display

During the second phase of the project, six experts in industrial engineering, health informatics, computer science, and nursing viewed 16 virtual homes representing each of four home types (detached, semi-detached, multi-unit, and mobile). The experts were allowed a maximum of 15 minutes to walk through each home, using the lab's VR CAVE, and select items using a tracked 3D wand VR input device, to "tag" items, that these experts believed would either facilitate or inhibit performance of specific PHIM tasks.

The wand is a common form of VR input device, akin to a 3D mouse, with an analog joystick for navigation and buttons for programmable user input; its position and orientation is also tracked within the VR CAVE space. In the virtual environment, the wand acted as an interactive, virtual highlighter, enabling our participants to visually and virtually tag anything within the point cloud model of the home that related to PHIM. As the user aimed the tracked wand within the CAVE, a small sphere appeared at the end of the wand. Pressing a button on the wand created a yellow tint at the point of intersection with the point cloud model. These individual selections (tags) were then saved upon ending the visualization application.

Group debriefing sessions were held with the expert participants after each week of data collection. The combined tags created by different experts tagging at different times in a single home were overlaid to produce a "heat map" of tagged features in rooms. Each expert's tags were assigned a different primary color, so that when tags overlapped, a combination of the two viewers' colors was generated (e.g. red + yellow = orange).

As a group, experts viewed these heat maps and then identified both objects and spaces in the home that were found to be commonly tagged. This process resulted in a cumulative list of features, both objects (for example, *nightstand*) and spaces (*kitchen)*, that were all confirmed by group consensus.

Tag Data Analysis**.** A master grid was then created in Excel of all *valid* tags generated by the expert participants in each virtual home. Valid tags are defined as those that were not reported as errors during the debriefing sessions. Overall, 68 unique objects were tagged, including expected objects such as calendars, clocks, and computers, as well as more surprising objects such as televisions, pictures, and stairs.

Subproject 3: Lay participants and data collection

A similar process was followed with 20 lay participants, all of whom self-reported as being told they have diabetes. These lay participants were asked to consider how they would manage PHIM tasks in each of the virtual homes they viewed. Specific PHIM tasks addressed were medication management, self-monitoring, and general health information management. Fifteen virtual homes were explored by these lay participants. A total of 39 home assessments were completed; one participant was unable to complete a second assessment due to unresolvable display issues.

A standard protocol for training, practice and home assessments was followed with each participant to enable standardized collection across these idiosyncratic, realistic home spaces. Slides were presented, explaining the participants' task and experiences in the virtual home assessment. A research assistant served as a guide for each participant. The guide remained with each person throughout the home assessment and documented the tags created as well as any utterances made when the tags were produced (e.g. "I always put my glucometer here (next to my bed) so I remember to use it as soon as I wake up"). A technical guide then explained the VR CAVE and the use of the wand, and conducted a practice session until the participant indicated they were ready to complete the assessment.

A 1:1 debriefing session was conducted after each house was viewed. A retrospective verbal protocol was designed to confirm the lay participant's tags and document the stated reason for the creation of the tags. Debriefing was conducted by doctorally prepared research team members with considerable experience in interviewing participants. The participant and debriefer viewed, on a 4K resolution, 28-inch monitor, a playback of their exploration in each house. During this session, all tags were reviewed and confirmed and any documented reasons for tagging a feature were explored. Missing features and erroneous tags were explored and corrected. The feature, room and notes were documented on a .pdf fillable form initiated by the guide and finalized by the debriefer. The debriefer-captured features and notes were considered the "gold standard" and were used thereafter for analysis purposes.

Overall, 54 unique features were tagged, for a total of 73 features from expert and lay participants in these two phases of the study.

Subproject 4: Visualizing and naming VR data

Utilizing the list of tagged features, it became possible to analyze data further. The goal was to further refine our list of objects according to their perceived usefulness for PHIM. Therefore, it was helpful to add functionality to the visualization application, so that a user could virtually choose an entire object -- as opposed to simply highlighting points. This function added a degree of interactivity to the technology. To enable users to select entire objects within the point cloud model, individual points comprising the objects were segmented by drawing a box around the points. To create the boxes, student project assistants used 3D software called SCENE (Faro Technologies; www.faro.com), bundled with the LiDAR scanner, that provides various user interface features for analyzing point cloud data. Once a box is created, a name for the household object can be attached to the virtual data. We developed a taxonomy of features and used this taxonomy to apply strict naming conventions – for example, a kitchen cabinet would have a box label of *K_cabinet2*. Analysis of specific PHIM tasks could then proceed. Boxes, once created are exported from SCENE and fed into the visualization application; in the CAVE, red outlines of the boxes appear, indicating to the user that the corresponding object is selectable. This form of data representation, 3D boxes representing "point objects", together with providing the user an ability to select these objects in the CAVE, would serve as the data collection mechanism for subproject 4.

Subproject 4: Citizens collect virtual data

Sixty laypeople who reported being told they have diabetes participated in this phase of the project. As in the previous phase, a scripted training session was conducted and a standard protocol for the home assessments was utilized. Instead of exploring complete homes, lay participants explored five rooms from different houses focusing on each of three standard PHIM tasks (medication management, self-monitoring and general information management) in successive sessions. The virtual renderings represented selected rooms from 10 homes representing each of the four principal home types (detached, semi-detached, multi-unit, and mobile). Subproject 4's goal was to refine the list of features already determined to be useful for PHIM by observing participants' sensitivity to them in different household settings. It was then necessary to produce a prioritized enumeration of the features identified by the experts and lay participants in the previous phases of the project. This prioritized enumeration would serve as the basis for the development of the Assessment of the Context of the Home Environment (ACHE). ACHE features in the final phase of the vizHOME project; its aim, described below, is to determine the presence and location of the features that participants identified as most useful for PHIM, in the context of a public health-oriented community survey.

To allow our lay participants to tell us what priority they assigned to different features and spaces, a list of boxed data from SCENE was exported to a format compatible with our point cloud viewing application in the CAVE. This enabled our participants to select entire boxes, instead of simply tagging.

The wand could be used to select at most two boxes in the CAVE. This made it possible to constrain participant choices to the particular PHIM tasks on which they were focused. For example, participants in the virtual kitchen could be asked: "Which object would be most useful? If there's another one, choose that." And reminded: "You don't have to choose any objects!" As the participants selected something in the CAVE, a change in color would occur and the box would be filled in, giving the participant a visual cue that it had been selected.

The resulting data is written out to a .csv file. This exported data thus provided not only the name of the feature selected, but the priority of its selection by the participant-- including no selection at all.

Data Analysis Tool: Visualizing VR data. To analyze data from Subproject 4 and make it easier to visualize and discuss, an analysis tool was created in QT (a cross-platform GUI API) to load multiple .csv files and summarize participants' selections across objects and across rooms. This enables team members to rapidly view participant selections while collapsing data features such as rooms, houses, participants, or PHIM features. To enable a more human readable analysis, the tool generates a heat-map with colors that can be assigned back to objects in the CAVE, enabling a visual representation for analysis of location and proximity of features and objects to each other. This was necessary because in one room-- for example, the kitchen-- several different features with the same name – for example, the cabinet – could be found in specific locations; however, the labeling scheme could not represent a particular cabinet in a particular kitchen. Associating the selection frequency data with a visual representation of the object allowed for further analysis and consolidation for development of the ACHE instrument, as well as provide interpretive freedom. The ultimate goal of vizHOME is to understand health information management in the home. Recontextualizing of features in household spaces, in *context* of the lived occupant experience, was necessary in order to make inferences about participants' possible reasons for selection.

Subproject 5: From virtual data to data collection instrument

The vizHOME team is working in collaboration with a long-running research study at the University of Wisconsin-Madison School of Medicine and Public Health, The Survey of the Health of Wisconsin (SHOW). This is a statewide public health survey designed to improve health in Wisconsin, conducting annual health surveys with longitudinal follow-up and enabling community-specific ancillary studies (of which vizHOME is an example). SHOW currently has a cohort of over 6,000 participants (adults and children) followed longitudinally. In addition to providing a type of research registry for vizHOME, SHOW will administer the final vizHOME product, the inventory of household features called the Assessment of the Context of Home Environments (ACHE). The ACHE will document the presence and location of the key useful features in a sample of more than 200 homes across the state.

**Discussion**

We have presented this research to illustrate the use of technology to design technologies, by presenting and capturing data from targeted end-users. The more we engage with the data of the home, the more data teaches us about the home and the more customized technological solutions can be to the person who lives there. [9]

For example, proximity seems to matter. In the case of household features such as cabinets and tables, this means data collection must consider not only the *presence* or *absence* of an object, but also its location relative to *other* objects. This leads us to ask: What does proximity have to do with PHIM? For wound dressing changes, proximity to a bathroom or kitchen sink matters. For self-reminders, putting something on a nightstand may serve as a cue to use at retiring or waking times. vizHOME researchers who visited these homes learned, for example, that medications were frequently set up and taken from a counter because a source of water was nearby. Occupants who tested blood sugar preferred a space that had ready access to a sink for hand-washing.

We also recognize that the home has its limitations. The variability of individuals' homes is a rich source of data about how people live and manage their health information, but that very variability means that features not seen are features not understood. For example, although the population of household occupants self-reported living with diabetes, no glucometers were captured in any of the LiDAR scans of their houses. Were these glucometers hidden, or are they unobtrusive?

Finally: working with tag data enabled us to discern an interesting difference between the lay people and the experts. While only 54 features were tagged by lay people, the experts presented with identical virtual homes tagged 68. One possibility for this difference is that for our lay participants living with diabetes, their task was interpreted as *actual* as opposed to what the experts heard as the experts were more expansive in identifying what they considered *potentially* useful for health information management; while lay participants were more likely identifying what they *would* use for PHIM. Thus, experts were not defining the utility of a feature using their own individual experience as a benchmark; laypeople who could identify primarily as people living with a chronic illness, and who were selected primarily on that basis, conversely, made their own individual experience paramount. Where the experts asked: "Could this feature, this room, be used for PHIM?" the lay participants asked instead: "Would I use this feature, this room, for PHIM?"

**Conclusion**

Working with the personal and idiosyncratic spaces of individually variable citizens has demonstrated to us the need to tailor data collection instruments, not only to the individual being assessed, but to the context in which that individual lives and uses the technology.

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