Effective personal health information management (PHIM), including symptom monitoring, medication management and clinical care coordination, facilitates self-care, ensures appropriate use of health services, and improves health outcomes. Computer tools can assist with PHIM, but these solutions are often created with little attention to where they will be used. The visibility of a calendar for reminding one of a weekly blood test or the proximity of a Bluetooth-enabled glucometer to the computer that stores the readings can enable or interfere with PHIM. Designers must understand where PHIM occurs to make optimally effective solutions. Yet bringing designers and engineers into the private, personal spaces and allowing repeated, systematic study of home contexts is not only burdensome to the home dweller, but also infeasible due to the ever-changing nature of homes. The purpose of this project is to systematically determine how household context shapes personal health information management.

Using Venkatesh’s (1996) model of the five environments of health to explicate the environmental context in the SEIPS work system model, we will (1) undertake an extensive study of 20 households addressing the social, physical, psychological, technical and health services context of PHIM, including creating detailed photographic, video, and 3D reconstructions of these households in a virtual reality CAVE; (2) through recursive immersive exploration in the CAVE, enumerate the features of these households that shape PHIM; (3) enlist 20 people self-identified with diabetes in a requirements validation activity in the CAVE; (4) engage 60 people with diabetes in an experimental evaluation of these indicators and (5) use all of these results to develop and evaluate, in a field assessment of 200 households, an Assessment of the Context of Home Environments inventory. The reference set of 20 virtual homes will be distributed through Creative Commons for repeated studies by designers. We will also make available the Assessment of the Context of Home Environments (ACHE) protocol for rapid assessments of the home context. This interdisciplinary project brings together nurses, engineers, computer scientists, and health services researchers to explicate how the home context shapes health information needs and can be used to guide the design of consumer health information management solutions.

As health care migrates from the institution to the home, and engagement of everyone in healthy practices is necessary to avoid disease or mitigate its consequences, systematic understanding of how homes will foster the integration of technologies into the every-day lives of people that ensure that homes not only become spaces for health but tools that draw people towards optimal well-being.
1 SPECIFIC AIMS

The purpose of this project is to systematically determine how household context shapes personal health information management (PHIM). PHIM encompasses a suite of cognitive and behavioral tasks that people undertake to accomplish their health goals, including: recording symptoms; communicating with clinicians; determining when and how to reorder medications; monitoring health states; and making sense of discharge summaries, health-related web sites and clinician-provided handouts. Often 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 the cognitive and behavioral tasks. Knowledge of which features of the household context shape PHIM can be used to better design technologies for PHIM. Our long-term goal is to improve individuals’ self-management and health outcomes by accelerating the design and adoption of PHIM-supporting computer technologies that explicitly take into consideration features of the home context.

Community-dwelling adults who self-report as having diabetes represent an ideal population around which to center our exploration of PHIM and households. Although the disease is manifest differently in different people, people with either Type 1 or Type 2 diabetes share a number of self care tasks they must do (e.g. self-test for blood glucose level, determine how much insulin or hypoglycemic medication to self-administer, recall clinician guidance regarding activity/food balance). Each of these tasks has associated PHIM components (e.g. recording and communicating blood glucose, retrieving and applying decision rules, storing pamphlets provided by clinician). The physical layout of the house can affect the performance of PHIM for the person with diabetes – spaces may or may not afford privacy for self-monitoring, visible memory aids like charts can assist in blood testing and insulin management, and file drawers can hold pamphlets. While it is long-recognized that health behaviors result from a complex interplay between people and their environments (Lawton & Nahemow, 1973), developments in computer technology, specifically virtual reality, now afford a safe and efficient way to apply intense scrutiny to this interplay in the household context. In this 5-year research project we propose to probe deeply into the visible, physical aspects of the home environment that influence PHIM. We will conduct a series of home assessments, laboratory studies and a field survey 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 household context on PHIM?

We propose to conduct a comprehensive assessment of health information management in 20 households of persons who self-identify as having diabetes with particular emphasis on the features of the physical environment (internal spaces and objects) likely to shape PHIM. As a mechanism to explore PHIM, we will observe the participant in three tasks common to people with diabetes: self-monitoring, medication management, and communication. Using image surveying technologies we will create complete digital models of each household. We will then display the digital models in a fully-immersive Cave Automatic Virtual Environment (CAVE), a 10’ x 10’ room in which coordinated projectors create 3D realistic-appearing renderings of the actual homes. The CAVE allows all models to be not only experienced in 3D, but also at scale, so that a participant can ‘walk through’ the virtual rendering of the actual house. Once we appraise the accuracy and realism of the virtual households, we will conduct requirements assessments in the recreated households. This will allow us to systematically appraise the interplay between social structure, task and physical environment, and generate an inventory of key features of the home context that affect personal health information management.

With a multidisciplinary team of clinicians, engineers, and computer scientists, we will determine which contextual factors of the home influence people’s awareness of, and ability to complete, information-dependent self-management tasks. This work represents an early exploration of how context shapes information needs – and will provide preliminary guidance to computer solution designers about how technology must fit within homes. Our conviction that context shapes information management challenges is supported by the strong evidence that the way people do self-management tasks varies by place (Provencher et al 2012) coupled with a paucity of specific knowledge about those different spaces (e.g. Lester, 2012; Unwin et al 2012). Yet understanding PHIM challenges in the home requires more extensive observation and study than possible in a single visit or a cursory observation phase; it requires more than can be done within the time parameters of a typical home visit. These constraints can be removed by re-creating actual homes in immersive virtual reality,
thus allowing repeated, non-intrusive visits to spaces. In our project, a specific home could be recreated in the CAVE, and revisited multiple times by the household members, by design teams with specific understandings about health at home, and by people who share similar health concerns. At the end of our project we will create a repository of full digital models of households that can be used in subsequent design activities.

2 RESEARCH STRATEGY
2.1 BACKGROUND AND SIGNIFICANCE
2.1.1 High-tech Health In The Home
The rapid migration of health care from the institution to the home and the concomitant rise in consumer health technologies calls for new ways to better characterize how this residential context of care shapes individuals’ health information needs and their abilities to meet them. Active patient participation in health promotion and disease prevention is recognized as essential to accomplishing the goals of Healthy People 2020. There is over 20 years’ of evidence of the positive outcomes when lay people use computer systems for personal health information management (Brennan et al 1991, Brennan, Moore & Smyth, 1996; Gustafson, McTavish, et al, 1998; Brennan, Jones, et al, 2001, Czaja et al, 2006; Demiris et al 2008; Charness & Boot, 2009; Brennan, Casper, et al 2010; Bowles et al 2012). However, there is growing evidence that better understanding of the household context where these technologies are being used might lead to both clarification of the health information management challenges faced in the home and improved design of the technologies intended to be used there (Or, Karsh et al 2011; National Research Council, 2011)

The context we will study are private residences (also referred to as homes, households, dwellings, etc). Homes are intimate, highly personal spaces and shape both consumer health information needs as well as the personal health information management strategies needed to respond to them. The layout of rooms, availability of storage space, presence or absence of visual cues like calendars can increase or decrease privacy concerns, ability to locate critical information or one’s ability to remember a clinic appointment. We employ the Medical Expenditure Panel Survey (MEPS) definition of “home” – i.e. anywhere the person is living at the time that a health care encounter occurs. It may be the residential unit (RU), member's home, the home of a friend, a hotel room, etc., but not a hospital, nursing home, or other health care facility. To help focus our exploration of PHIM we will focus on the information management demands that arise in self-care for individuals with chronic disease.

While our target of exploration is the household, we will specifically focus on households involving people diagnosed with diabetes (thus fulfilling the AHRQ Priority Populations Inclusion Policy). Estimated to double globally from 171 million people in 2000 to 366 million people by 2030, diabetes is expanding both the amount of personal health technology many people use regularly (Wild, Roglic, Green, Sicree, & King, 2004) and the PHIM demands placed upon them. People diagnosed with diabetes have a large burden for self-management, including self-monitoring of blood glucose, observing for complications, managing an array of ingestible and injectable medications and demonstrating compliance with instructions from clinicians. Each of these tasks have significant information management demands (recognition, recording, communicating, interpreting) and many technologies are being developed to assist people to manage these. Situating this first investigation of how household context influences PHIM in the homes of people with diabetes is valuable because much of the management of this disease occurs in the home, interspersed with the daily lives of patients.

Better care outcomes are achieved through customizing aspects of the care to better fit the patient (Baker, et al., 2010), and that customization leads to home-based activities that must be undertaken by the person. Patients face many challenges in trying to meet the daily demands of self-management of diabetes (Ellis, et al., 2004), but recent research has shown that interventions that fit into the patient’s daily lives and draw on their skill set can have a positive impact on the diabetes measures (Trief, Izquierdo, Eimicke, 2012). They found that providing tailored goal-setting and problem solving case management to minority participants with diabetes had a modest, positive impact on insulin management. Innovative approaches to studying home-based self-care are growing, including embedding monitoring and sensor devices in home settings (Demiris, 2009; Helal, Cook, Schmalz, 2009). However these smart homes are prohibitively expensive, and cannot be built for every patient situation. The knowledge generated through the work proposed here will be instrumental in helping
researchers and designers identify the aspects of the home that impact information needs and PHIM and to accelerate design of effective technologies that support patient-centered care in the home.

There are over twenty years of calls for more systematic study of interior environments, yet little progress has been made. Home assessment is difficult because the spaces are highly personal and idiosyncratic therefore do not lend themselves to the same type of context assessments applied in formal work environments (Or, Karsh et al, 2009). Certain features, like the visibility of a calendar or the proximity of a glucometer to the computer that receives its blue-tooth signal to upload a reading, can only be discerned by visual assessment. Yet home assessment is time consuming (Carlsson et al 2009) and often requires experts (Marquard et al., 2011), particularly when the focus of the assessment is modifications needed to assure accessibility of a home (Sanford & Butterfield, 2005). Additionally it is not clear which aspects of the house are really important to examine to promote understanding of PHIM in the home context and design technologies to support it.

Groups have used various strategies to assess home spaces including self-report (MEPS), interview (Moen & Brennan, 2005), observation by research staff or professionals (Demiris, Rantz et al., 2004) Tania, 2012, video recording by clinical staff (Sanford & Butterfield, 2005) and drawings and photographs (Zayas-Çaban 2012; Marquard, Moen & Brennan 2006). These assessment strategies are influenced by the motivation for the assessment, often taking a physical ergonomic approach examining the way in which the physical characteristics of the interior environment or its contents evoke or interfere with the gross or fine motor function of the home dweller. In a complementary vein, our group (Moen & Brennan, 2006; Marquard, Moen & Brennan, 2006; Marquard and Zayas-Çaban 2011, Zayas-Caban 2012) employed macroergonomic approaches to explore the fit between a wide variety of health related cognitive and behavioral tasks and the home environment. However, we also experienced the limitations noted above (particularly a high degree of variability of internal environments and home dwellers’ reluctance to permit long visits by strangers), thus our ability to characterize the home environment was quite limited; we aim to rectify that problem in this project.

Information and communication technologies assist patients in self-management and enable them to be better participants in their care (Brennan, Moore & Smyth, 1995; Gustafson et al 2012). Patients with access to home care technologies that provided coaching and self-monitoring support recovered faster, and with fewer symptoms than those who did not have such access (Brennan, Moore, et al, 2004). Some device-based self-management tools enabled patients to have better understanding of the health care problems and gain an understanding of their condition; other devices provided quick and easy access to professionals (Shea, 2007) or peers who share common concerns (Demiris, et al 2008; Gustafason, Shah et al 2010), thus delivering both social support and practice advice. Largely the work in this area is decontextualized, focusing on the content of information needed by consumers (e.g. Gaglio et al 2011) or the activities undertaken to manage health problems (Pratt et al., 2001) or individuals’ motivation and skill in using computer technologies (e.g. Czaja et al., 2006). Evidence suggests that information needs may vary by the nature of the clinical problem (Marquard & Zayas-Caban, 2011) and the characteristics of the tasks (Unruh & Pratt, 2004); however these differences may also be attributed to the manner in which the environment where individuals live and face information needs evokes, inhibits, or presents barriers to health information management practices.

Several studies that have examined how household residents manage their health information have shown that households are complex socio-technical systems (Mentas et al, 1996; Hindus et al, 2001; Unruh & Pratt, 2004; Vitalari et al., 1985). Moen and Brennan (2005) employed a human factors model to examine what people actually do with the health information they search for and retrieve, where they are when using these resources, and how they integrate health information and resources in their daily lives. This human factors model, the Systems Engineering Initiative for Patient Safety (SEIPS) provides an integrated perspective in highlighting interdependencies among these factors (Carayon et al., 2006; Karsh et al., 2006, Or et al., 2009). Moen and Brennan (2005) employed this model to examine one PHIM activity: storage of health information in the home. Investigations of 49 households revealed that there are several information storage strategies employed by households: just-in-time; just-because; just-in-case; and just-at-hand. In a just in time storage system, the information and other artifacts are with a household member most of the time. In a just-at-hand system, the information is visibly stored in a readily accessible, highly familiar location within the household. In a just-in-case system, information and/or artifacts are stored away but are accessible within a reasonable time. Just-
because is a system in which health information is collected and kept, but because of temporal relevance, no specific storage system is identified. These different strategies reflect a synergy of location, information or artifact, and anticipation about future use (Moen & Brennan, 2005).

Assessment of the internal environment of the home is important (Whal, et al 2009) because it contributes to both the individuals' well-being and function, albeit in inconsistent ways, (Tania 2012) but the home context has primarily been studied from the perspective of elders and those with disabilities (Oswald 2011) with a goal to make the homes safer and more accessible. In line with this, assessment of the internal environment almost exclusively focuses on the structural characteristics of the dwelling (steps, mantles) or highly subjective experiences, such as the emotions engendered by the space (cozy, warm). Efficient study of the household environments that influence PHIM require both greater detail about the spaces and the tasks that individuals attempt to accomplish in them.

Architects, occupational therapists, home health staff and clinicians all share an interest in understanding the home environment of the home dwellers and the manner in which it influences how health tasks, particularly cognitive ones, are conducted. Examining the difference in cooking tasks between homes and clinics among 33 frail adult, Provencher and colleagues (2012) determined that the individual performance across environments (measured solely by the differences between placement of common household items) varied based both on cognitive function and psychomotor skill. Results of studies at this level will not fill the urgent need to provide guidance to patients managing complex medical procedures and information management tasks at home (Unwin, et al 2009; Lester, 2009).

Despite the importance of understanding the household environment in determining health information needs in the home, there are few ways to systematically study the physical environment of the home. Home visits can be intrusive and it is difficult to spend sufficient time to undertake systematic study. In addition, repeatedly accessing the same household is disruptive to the occupants. It is challenging and intrusive to bring an interdisciplinary team comprised of several people into the home; additionally, bringing several people into small intimate spaces obscures typical behavior. Some (Demiris, 2008) explored various home sensing approaches, including cameras and wall mounted sensors. The 34 people in Demiris’ study expressed a preference for passive sensors over cameras, perceiving the sensors as less intrusive. Cameras can provide a reasonable visual representation of small, intimate spaces however, garnering meaningful insights from such a process requires strong spatial awareness by the designer viewing the space (Sanford & Butterfield, 2005). Additionally, cameras reveal private behaviors that are not necessary to inform the process. Additionally, even if there were sufficient amounts of time, privacy-preserving tactics and willingness to participate, industrial engineers lack design methods guidance to help designers know what parts of the house are useful to focus on for design. Virtual reality recreations of existing homes may provide the needed resource for revealing how context shapes PHIM practices as well as consumer health IT design, adoption, and use.

Intense examination of actual households is necessary but infeasible, and it is literally impossible to undertake systematic repeated study of the same environments. Physical mockups of households do permit repeated study of actual environments (Pati, 2011) but lack the rich detail of lived-in homes and are expensive to create. Photographs and other static views of houses do not afford the experience of actually walking through the houses in which the PHIM tasks are performed. Virtual reality (VR) models of actual homes, rendered in CAVES, have real promise to mitigate these limits.

### 2.1.2 Health Applications of Virtual Reality

Virtual reality (VR) presents individuals with visual stimuli that afford an experience of being immersed in a place remote from where one actually is (Sanchez-Vives & Slater, 2005). Using 3D glasses and a specialized computer interface, individuals can experience sensory stimuli (visual, auditory, and tactile) to experience a sense of “being elsewhere”, known as a sense of presence. Therapeutic applications of virtual reality are growing, including mitigating chronic and acute pain through distraction interventions (Maani et al, 2011; Keefe et al 2012; Wan & Collins 2012), and managing phobias through rehearsal and visual feedback (Safir, Wallach & Bar-Zvi, 2012). Other health applications of VR include social support (Stewart, Hansen & Carey, 2010); psychomotor skills training (Ruthenbeck, Tan, et al., 2012) and health professionals’ education (Wiecha et al.,
In health care, one finds three primary implementations of virtual reality: through standard desk computer interfaces (most often those found in computer gaming and simulated environments such as Second Life™), head-mounted displays (HMD), and immersion rooms called Cave Automatic Virtual Environments (CAVEs) in which the walls serve as large-scale projection screens. Standard computer VR experiences draw the viewer’s attention to a desktop display and are not immersive. HMDs use a helmet-type device, tethered to a computer, to display coordinated images on two small over-eye screens. Because the screens are so close to the users eyes, the user sees only the rendered environment, thus replacing their normal view of the real world. This unfortunately means that users can no longer see their bodies, or those around them. Furthermore, the latencies involved with HMD cause a substantial increase in simulator sickness compared to a CAVE environment (Kennedy, 2010). In immersive VR CAVEs, participants use active or passive stereo glasses to view 3D images projected onto screens, thereby enabling users to still see their own bodies and other participants in the scene. VR CAVEs are large enough to allow participants to make whole-body movements. For the purposes of exploring how the home context shapes consumer health information needs and task performance, seeing one’s own body and others in the scene is essential, thus requiring a CAVE.

Our project is the first use of immersive VR for home assessment. Other, less immersive virtual environments, such as those displayed on a desktop computer provide a credible but impoverished experience of being in the home. For example, Sabus and colleagues (2011) created a Second Life household simulation to allow inter-professional students to assess and plan responses to home hazards. Second Life™ is a commercial computer platform that provides an online community that is mediated through 3D computer graphics. Second Life’s popularity has come from its interface design and ability to craft 3D scenes. Evaluated only through a single-group post-assessment, students found the experience added realism to the case study learning approach and faculty determined that students made modification recommendations that were both more patient-centered and fostered health promotion rather than disability mitigation. It is important to note that Sabus and colleagues defined VR differently from Sanchez-Vives and Slater (2005), and the setup they used would not be considered to be immersive, and therefore, for the purposes of our work, unsatisfactory.

Most VR experiments focus on the user behavior and interaction with specific objects; the emphasis is on ensuring that the user attains a sense of presence in the situation or scene (Slater, 2003); presence is a psychological state believed to be enhanced by the quality of the immersion and the sense of embodiment. Participants navigate through the virtual world by physically walking and through using 3D computer input devices such as a tracked wireless joystick, often called a wand. Objects viewed in VR, if they are assigned “physics” properties, can be manipulated (lifted, turned, or moved) (Normand, Giannopulos, Spanlang, & Slater, 2011). The visual cues of the scene need to be “good enough” to create the sense of psychological engagement. Often these scenes are impoverished, lacking the realistic color, hue intensity, and variability found in real environments. This is in part a consequence of the challenges, in creating sufficiently detailed image capture in real environments and displaying those in a CAVE. In our work, our attention focuses more on the ability of the VR to recreate actual environments. Therefore, assessment of the validity of the VR scene as a re-creation of an actual environment is quite important.

In this sense, it is important to recreate realistic home environments in VR with as much fidelity as possible. Environments created entirely in 3D modeling tools often lack the realism of physical environments, as it is difficult to recreate the environmental details, such as clutter on a desk. While previous researchers have attempted to capture environments through photographic devices such as a Gigapan (Ulrich & Norbakhah, 2000), these recreations present a static panoramic view of an environment that one can observe but not walk through. Even when these panoramic photos are presented in an immersive environment, users cannot change their points of view or traverse the space. For this reason, we plan to capture homes in full color 3D using a Light Detection And Ranging (LiDAR), a survey grade technology used for capturing environments. The LiDAR scanner produces a data set, called a point cloud, that records the 3D position and color information for all points in space. This point cloud data will be used to build high fidelity 3D models of the 20 homes that can be experienced in the CAVE system.
It is important to remember that the goal of this project is to discern how context shapes consumer health information needs and the PHIM strategies they employ to meet these needs; the VR CAVE is an experimental laboratory environment that will allow repeated, persistent and non-intrusive approaches to allow systematic characterization of the environment and discovery of how context shapes information needs and PHIM. The CAVE offers several additional advantages, for example, the ability to quickly add or remove objects from view, or to completely change from one immersive scene to another within a few minutes. We will identify characteristics of the environment, determine if they recur in other spaces, and produce both an enumeration of which aspects of the environment are important shapers of health information needs as well as a strategy to study those in future work in other environments.

2.1.2.1 Design Strategies Enabled In VR Including Requirements Definition

Design is complicated and calls for innovations, such as user-centered design that generally fall short of their goals because people often do not know, or cannot adequately express what they want in a design (Liu, 2003; Noble, 1993). This may be because they are trying to reconcile multiple goals, are not aware of their actual goals, or it is hard to for them to select from the infinite design options (Nathan-Roberts, Kelly & Liu, 2011; Nathan-Roberts & Liu, 2010). As a result, product designers often rely on trial-and-error, or use their own subjective judgments and heuristics instead of a data-driven approach to design (Otto & Wood, 2001). This use of designers’ judgments and heuristics alone can lead to a time-consuming process and potentially non-optimal solutions. While people may not be able to explicitly state all of their preferences, they can make selections that reveal them (Green & Srinivasan, 1990). For this reason, user-centered design approaches are used to elicit user-needs and preferences (Norman & Draper, 1986). User-centered design approaches are not new, but in the past have often lacked strong quantitative and theoretical frameworks (Liu, 2003). Therefore, a better way to design new products or systems is to involve users in a data-driven design process that systematically quantifies their responses (Dong & Ding, 2009; Kelly, Maheut, Petiot, & Papalambros, 2011). By systematically quantifying users’ reaction to design components, designers can even better understand user needs and preferences. The problem with user-centered data-driven design processes is that they are highly invasive. In the course of the experiment, they make large changes to the interface, workflow, or other aspects of the work system. For this reason, user-centered experiments are generally conducted in simulations (Anders et al., 2012; Chan et al., 2010) in which the environment can be highly controlled (Nathan-Roberts et al., 2011; Nathan-Roberts & Liu, 2010). In the proposed work, we will use the SEIPS model to examine which potentially intervening variables may change users’ perceptions of the space and interfere with the in-depth user-centered design requirement.

The work proposed here addresses two research areas of interests from the AHRQ PA-11-199, specifically, 1) the needs and preferences of diverse user groups in different contexts; and 2) user goals, activities, and personal health information management practices. Our work builds on and addresses previous AHRQ and National Research Council (2011) efforts addressing consumer health information needs. By examining how context shapes health information needs and personal health information practices, we are addressing recommendation #2 from the Consumer Design Guide Information requirements assessment: Strive to understand consumer needs within the environment that the product will be used… (Westat, 2012). That guide, intended to bring lessons from successful consumer electronics design to the consumer health IT initiatives, found very little beyond expert judgment and inspiration to guide design choices. A challenge revealed during the key informant interviews was that designers lacked efficient ways to assess consumers in their everyday environments. The first step towards filling in this gap is to provide an enumeration of the key areas of the home environment that merit focus for designers; we will create and validate an inventory of features of the household that shape PHIM. Additionally, we will build and disseminate through Creative Commons a reference set of 3d digital images of the interiors of 20 dwelling that can be used for inspiring design and permitting systematic study. Our work will both generate new knowledge about PHIM as well as build new design tools.

2.1.3 Informing Future Research, Other Real World Implementation Efforts, and/or Consumer Health IT Design
Our project takes a principled, integrated approach to enumerating which factors of the home environment influence health information needs and management, evaluates them using experiments in a virtual reality CAVE and then employs a large field appraisal to discover the naturally occurring variability in these factors. What must happen next is to take the inventory of home features developed here and generate evidence of how technologies mitigate or compensate for these features. Systematic studies based on a stable enumeration of the features of homes that shape PHIM will move design principles beyond intuitive expert judgment to systematic strategies as called for in the recent spate of reports on consumer health informatics and human factors in the home (NRC, 2011). Yet simply publishing one more set of papers is unlikely to garner the attention of designers; they also need access to a test environment that can both serve to inspire as well as provide standards against which to evaluate design ideas. To address this pressing need we propose to create and distribute under Creative Commons each of the twenty 3D models of home environments we will create in this project.

2.2 THEORETICAL FRAMEWORK AND PRELIMINARY STUDIES

2.2.1 Theoretical Frameworks

The project will be guided by the SEIPS model, the Systems Engineering Initiative for Patient Safety (Carayon et al., 2006; see Figure 1 below). This model posits that the work system, a structural concept, influences how processes occur, which in turn shape outcomes. The health care work system is defined as the integration of a person attempting one or more tasks using a given suite of tools and technologies in a specific physical environment influenced by the policies and procedures of a specific organization. We translate this to the home context, in which the person is the lay individual who is attempting self-management tasks for self or others using the available supplies, computer tools and resources in the informal household environment following the culture, family practices and other influences on intimate life at home. In this project we will focus on the work system in the home, with particular attention to aspects of the physical environment and personal health information management tasks. We first need to explicate the concept of the home environment.

We employ the useful rubric provided by Venketesh and colleagues (2000) for elaborating the health environments surrounding an individual. They conceptualize the home environment as consisting of five elements: the social environment (who does one live with and share health management practice with), the physical environment (where), the psychological context (the individual’s knowledge, skill and ability), the technological environment (both internal and external to the dwelling) and the health systems context (what access does the individual have to health services). In this project we will focus specifically on the physical environment, attending to the interior spaces of home dwellings and the objects within those spaces. We will monitor other aspects of the physical environment (temperature, sound) but do not plan to manipulate those experimentally.

The SEIPS Model provides an overall roadmap of the personal health system; Venketesh’s typology explicates the elements of the environment we attend to, and we employ Gibson’s ideas of affordances (Greeno, 1994) to enrich and make explicit how context shapes information needs and PHIM. Affordances are the characteristics of objects or environments that give cues to action – e.g. a knob on the right invites one to turn it to pass through a door, a sign over a slot in the wall denotes where one leaves mail in an apartment lobby. Interior environments have affordances that evoke in those who observe them the set of possible behaviors or actions. For example, a calendar on the wall may remind a person of a clinic visit; instructions printed on a card and affixed by rubber band to an insulin bottle can help a patient determine how much insulin to administer given a recently obtained blood glucose reading. But if the calendar is taped to the inside of a cabinet, or the...
insulin bottle lost in a messy refrigerator, the affordance of these objects is diminished. Thus, environments could either evoke or dampen information needs and the capabilities of responding to them based on features of the environment. Thus we will study the physical environment of homes to determine how the affordances of the interior spaces and objects within it enhance or interfere with PHIM.

2.2.2 Preliminary Studies: Our Team Is Well-Prepared to Do this Work
Our multidisciplinary team brings a unique and essential set of skills to this project. Brennan has over 25 years’ experience developing technologies for and evaluating them in the home. An internationally recognized leader in the area of personal health information management, Brennan directed or oversaw home care technology innovation projects involving over 1000 households in work as diverse as evaluating the impact of internet-based support services for people with AIDS (ComputerLink; NR 2001, 1987-1992 Brennan, Moore & Ripich, 1991; Brennan 1997); for caregivers of persons with Alzheimer’s Disease (AD ComputerLink AG 6247; 1988-1992; Brennan, Moore and Smyth, 1995)) web-based, hospital-to-home transitional care for patients with chronic cardiac disease (HeartCare NLM 6247; 1996-2005) and Project HealthDesign, an RWJF-funded multi-site initiative to accelerate PHIM tool development from solely records management to self-care decision support (2003-present; Brennan, Casper and Downs, 2010). The Design Consultant process (two-day immersive experiences) developed in Project HealthDesign will form the basis of the requirements definition process used in the present work.

Brennan’s work revealed that while patients are willing to use a wide range of technologies to support self-management, existing technologies carry with them too many presumptions about such factors as lighting, stability of electrical power, Internet access, and interpersonal privacy to fully support technologically-enabled health care in the home. Brennan’s early work, funded by Intel, revealed the complex and functional ways patients in the home devise effective workarounds to manage health information (Moen & Brennan, 2006); this work provides the basis for the interview and home assessment guide proposed in this project. Thus, with the support of interdisciplinary teams, Brennan demonstrates substantial experience in identifying home-dwelling participants, keeping them engaged in intervention-based projects for as long as one year, and recognizing both the potential and the limits of technologies designed without adequate understanding of the context of use. The present project is a realization of a 20-year goal to reduce patient burden and provide better tools to patients by incorporating concepts of household context early in the design process, thus affording better, more acceptable, and more useful tools. The first step is to systematically study the environment for cues from the context that help shape information requirements and personal health information management.

Kevin Ponto, PhD, began working with Brennan in 2010 and brings considerable computer science and aesthetic design skills to the team. For this project his practical experience using LiDAR technology to capture internal environments is essential, as is his recent work in creating natural interactions with virtual spaces (Ponto et al. 3DUI, 2012) and developing effective tools for conveying experiences for outside observers (Ponto et al. TVCG, 2012), both under NLM 5T15LM007359. In May 2007, Ponto, a graduate student at the time, was flown to Florence, Italy to create 3D models of the Palazzo Medici Riccardi, the Hall of the 500 in the Palazzo Vecchio, and an abandoned convent. The team from UCSD employed a LiDAR image capture, similar to the one proposed for this project, to create a 3D point data representation of every space in the interiors of the identified buildings; the team was then able to display those data files in a VR CAVE, thus allowing participants in California to virtually walk through the buildings as they actually existed in Italy. In our case the LiDAR scans will enable the creation of rich, colorful detailed models of home environments.

Dan Nathan-Roberts, Ph.D., is currently an AHRQ postdoctoral fellow working with Brennan and Carayon; he is anticipated to formally join UW Madison following that. Nathan-Roberts and Carayon currently conduct focus groups and home interviews of chronically ill patients to better understand patient perspectives of care as part of the ONC’s Keystone Beacon Project. Nathan-Roberts brings strength in physical ergonomics and context (Nathan-Roberts, Chen, Gscheidle, & Rempel, 2008; Rempel, Nathan-Roberts, Chen, & Odell, 2009), the human factors of design, (Kantowitz & Nathan-Roberts, 2009; Nathan-Roberts, Liu, Young, Hays, So, Christian, & Zhao, 2009, Nathan-Roberts, Kelly, & Liu, 2011; Nathan-Roberts, & Liu, 2010, Nathan-Roberts, & Liu, 2012), innovation (DeGraff & Nathan-Roberts, 2011), and was an Oak Ridge Institute for Science and Engineering fellow at the Food and Drug Administration, as well as an Intel telemedicine intern.
Four years ago our group proposed and created the Living Environments Laboratory at the University of Wisconsin-Madison’s Wisconsin Institute for Discovery (www.discovery.wisc.edu/lel). Established purposefully to allow the re-creation of the physical environment of any household on earth, the LEL employs state-of-the-art VR in a room-sized space called a CAVE. We have established a proof-of-concept household in the CAVE - an apartment that includes a living room, kitchen, bathroom and outdoor spaces. Over 2500 people have visited the apartment during the past 20 months; we have learned that it is possible for lay people to enter and navigate through virtual spaces. Importantly, we have learned the limitations of abstract re-creations of human living spaces; notably that designer’s re-creations lack the visual clutter and affordances found in real households (that is, the virtual home is ‘too neat’). Fundamentally this observation is what has confirmed the need to render REAL households in the VR space to enable further study of PHIM in context, and to extract from the context the design requirements that shape PHIM.

Carayon and Hoonakker, consultants to this project, have ample experience in conducting interviews and observations of work system and processes: they have examined processes in a variety of care settings and patient populations: in Intensive Care Units (ICUs) [CPOE-ICUs, RWJ project, NSF project on tele-ICU], in outpatient surgery settings (Carayon et al.), and care coordination for COPD and CHF patients [Keystone Beacon Project funded by ONC in collaboration with Geisinger]. They have experience in visiting homes and talking to patients in their home: [ONC project with Geisinger]. Brennan and Carayon collaborated in the HeartCare program (described above) for 8 years, and are in the same department in Industrial and Systems Engineering.

The **Survey of the Health of Wisconsin** (SHOW) team joins Brennan and her team for the first time in this project as a partner for reaching residents in the community. The SHOW is modeled after the Center for Disease Control and Prevention’s National Health and Nutrition Examination Survey. SHOW is funded by the NIH’s National Heart Lung and Blood Institute, the Wisconsin Partnership and the UW Institute for Clinical and Translational Research. Under the direction of Dr. F. Javier Nieto and his team at the University of Wisconsin’s School of Medicine and Public Health, the SHOW team includes experts in population health research from the UW Department of Population Health Sciences, the Center for Urban Population Health in Milwaukee, the Marshfield Clinic Research Foundation and consultants from multiple UW departments and around the nation.

The SHOW has been conducting annual surveys since 2008, and at the beginning of 2012 has a growing cohort of over 2,500 Wisconsin adults - which SHOW will follow longitudinally. In this project, we will partner with the SHOW team to identify participants for the household surveys, for subsequent design exercises, and for the validation of the inventory that will form one of the products of our work, the Assessment of the Context of Home Environments (ACHE). Participation of the SHOW team assures a reference-sampling frame so that our team will be able to determine the extent to which the sample extracted for the vizHOME study is similar to, or different from that of the region. Collaboration with SHOW also affords the ability to compare our sample with the larger statewide sample and national trends in MEPS. Thus we will be able to appraise the generalizability of our sample and our findings, and explore health-related and neighborhood correlates.

### 2.3 RESEARCH DESIGN AND METHODS

#### 2.3.1 Overview

In years 1 and 2 we will conduct in-home assessments and image capture in 20 homes identified by the SHOW project so that by the end of this period we will have 20 sets of data, providing an enumeration of tasks done in twenty different houses, profiles of the houses in terms of the physical aspects, layouts, and space orientation. We will conduct intensive assessments in each home, including profiling the primary respondent, observing his or her performance on three information intensive health care tasks, and using a standard camera and LIDAR technology to capture images of the home. Research questions to be resolved by the end of year 2 are whether tasks vary by the home environment within which they occur. During year 2, we will also evaluate the fidelity of the house visualization, and conduct performance testing on the virtual houses. Following the Design Consultancy strategy employed in Project HealthDesign, we will bring our team together for two-day design workshops every two weeks, to walk through the virtual houses, and, guided by Nathan-
Roberts, to extract design requirements. Our primary approach for requirements definition will be based on Gibson’s ideas of affordances applied to PHIM (Greeno, 1994). We will examine household structures, objects, and clusters of objects to determine what affordances exist or do not exist. We will generate multiple characterizations of context-shaping information requirements in the virtual houses, and, following a consensus process, develop an enumeration of key features of the home context likely to influence PHIM. In years 3 and 4, we will bring lay people who share similar health concerns into the CAVE’s virtual houses to validate the requirements arising from these contextual insights or to suggest new ones. During years 4 and 5, we will further evaluate the generalizability of the enumeration of the aspects of the context that shape PHIM through a sample of 200 individuals gleaned from the 2016-7 SHOW participants.

Summarized below are five sequential but interrelated sub-projects within this project (Table 1):

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Subproject</th>
<th>Main Activity</th>
<th>Method</th>
<th>Participants</th>
<th>Key Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 Section 2.3.2</td>
<td>Home assessment and rendering of the homes in virtual reality</td>
<td>Field assessment</td>
<td>20 adults with diabetes and their dwellings</td>
<td>60 task flow diagrams (3/house) Replications of the 20 dwellings in the CAVE</td>
</tr>
<tr>
<td>1</td>
<td>2 Section 2.3.3</td>
<td>Information Requirements Definition</td>
<td>Design workshops</td>
<td>Investigator team</td>
<td>Preliminary List of household features that shape PHIM</td>
</tr>
<tr>
<td>1</td>
<td>3 Section 2.3.4</td>
<td>Requirements Validation [Top Down]</td>
<td>Lab study (In CAVE)</td>
<td>20 adults self-identified with diabetes</td>
<td>Refined list of household features that shape PHIM</td>
</tr>
<tr>
<td>2</td>
<td>4 Section 2.3.5</td>
<td>Requirements -Experimental Manipulation [Bottom Up]</td>
<td>Lab Study (In CAVE)</td>
<td>60 adults self-identified with diabetes</td>
<td>Prioritized list of household features</td>
</tr>
<tr>
<td>2</td>
<td>5 Section 2.3.6</td>
<td>Assessment of the Context of Home Environments Inventory</td>
<td>Field Survey conducted by SHOW</td>
<td>200 adults subsampled from the SHOW panel</td>
<td>Validation of incidence and prevalence of household features</td>
</tr>
</tbody>
</table>

Table 1: Overview of the research strategy

2.3.2 Subproject 1: Home Assessment and Rendering of Homes in VR (Brennan, Ponto, Casper)

2.3.2.1 Purpose
The purpose of the home assessment and rendering of homes in VR subproject is to generate accurate and complete descriptions of 20 actual homes and the ways in residents there carry out the information management components of three common health tasks. This is a non-experimental observation study.

2.3.2.2 Setting and Sample
The setting for the home sample phase of this project is central Wisconsin, a region of the country that includes both rural and urban areas. The unit of analysis in this study is a dupe: key informant and the dwelling (RU in the MEPS parlance) in which that individual lives. We will select five of each dwelling type: detached single unit house, semi-detached, attached multi-unit housing and movable dwellings. While there is no statistical rationale for the sample size of 20, our experience with health care in the home supports that we will capture sufficient variability to inform subsequent subprojects.

2.3.2.3 Sampling Plan
We will employ a two-stage sampling plan to recruit a sample that meets the AHRQ expectation of targeted populations. We will partner with the Survey of the Health Of Wisconsin (SHOW) project.
(http://www.med.wisc.edu/show/survey-of-the-health-of-wisconsin/35828) to leverage their proportionate sampling strategy and established community relationships. First the SHOW team will identify potential key informants who represent a residential unit (RU, the MEPS term for the group of individuals who live together in a house) and then enroll qualified participants sequentially until we have five exemplars of each of the four housing types. Inclusion criteria include self-identified with diabetes; having a current and anticipated 6-month long residence in one of four types of houses; self-identified ability to speak, understand and write in English; and willingness to participate in the household assessment process. Currently, about 10% of the participants in the SHOW sample (100) self-identify as diabetic. We expect to recruit 10% of these (about 10 per year) and enroll two to three participants a month, and will enroll a sufficient sample between months 6 and 16; allowing for drop-outs and incomplete data collection (data from households that did not complete the full data collection will be retained for comparison purposes only).

In each of the twenty households, the key informant will be a person self-identified with diabetes. The key informant will be the point of negotiation for all home visits. Because some of the processes may involve other members of the household, permission for inclusion and the additional data will be collected from these individuals according to the approved human subjects protocols. In a manner similar to snowball sampling, these individuals will be identified during the interview with the patient. Whenever the patient mentions that a household member is involved in a specific process, follow-up data collection will occur through speaking with that household member about their particular role in the process.
2.3.2.4 Procedure
2.3.2.4.1 In Home Assessment
Each home assessment will require 5-6 home visits, arranged at the convenience of the home dwellers, over a 5-6 week period. We will use questionnaires and observation strategies. Brennan will be responsible for the oversight of the home assessment; Casper will work with Carayon and Hoonakker to finalize the protocol and train home visitors. The responses of the key informant of the RU will be assessed following the SHOW protocol. If the RU resides in a house category still not filled in our set of four house types, the participant will be invited to become enrolled in the main project. Project activities will be explained to the individual and project expectations and compensation will be revealed. The first visit will occur entirely under the existing SHOW protocol and will take approximately four hours. An instrument and variables to be assessed by the SHOW team at visit 1 are included in Appendix 1. Data collection will be completed and arrangements will be made for the home-based assessment.

The five (six, if needed) visits and the primary tasks are as follows:
Visit 1: SHOW team baseline assessment and gain permission for full participation in the main study
Visit 2: vizHOME team task process analysis and SLR photography
Visit 3: vizHOME team confirmatory process analysis and introduction of the LiDAR assessment team
Visit 4: vizHOME team LiDAR scan; layouts and health information maps
Visit 5 vizHOME team in-depth assessment of key elements in the environment
Visit 6 vizHOME team finish and image collection scanning if necessary

The first visit will be conducted by a member of the SHOW team at which point the permission for a more extensive study will be obtained. This visit will collect demographic information and a baseline characterization of the household. Visits 2-6 will involve two people from the vizHOME team. We expect to schedule the visits about one week apart so as to not burden the home residents. Casper, supported by Hoonakker and Carayon, will train home visitors in the skill set needed to ensure professional, respectful interactions with the home dwellers, home visit safety, and strategies to minimize intrusion in the home space. One visitor will be primarily responsible for interacting with the key informant; the second visitor will be responsible for the observation strategies. This number of visits is necessary to build trust with the key informant, to develop sufficient familiarity between the household and the assessment team to mitigate the RU’s need to stage the home in a manner that obscures the typical layout, health task completion, and information flows. Permission will be sought before interacting with any individual, and for entering any of the home spaces. Where possible we will ask home dwellers to guide us on a tour of their homes, and will, as our home visit team progresses, request permission to photograph in more detail or to move objects if necessary. In recognition of the degree of inconvenience that this might cause for home dwellers we will provide each RU with $750 compensation.

Visits two and three will focus on task assessment. Visit 2 will include two research team members; one will focus specifically on task assessment, the second will take photographs. This visit will begin with an interview of the primary informant in the household. Data analysis outputs will be presented to the patient and other relevant members of the household. We will ensure that the data analysis outputs are correct and complete. We will administer a survey targeted at identifying work system barriers and facilitators to performing the key processes. Whenever processes involve other members of the household they will be interviewed about their role in these processes. Task observation will occur and be documented in a flowchart (Appendix 2). During visit 3 validation of task assessment, member checking and preparation of the home for LiDAR data capture will occur. We will take photographs on this visit also. On Visit 4 we will complete the low resolution LiDAR scan that will be re-viewed in the CAVE. Visit 5 is a confirmation and replication visit that may include a more intensive LiDAR scan in places where high levels of resolution are needed, and will include image data collection, and drawing layouts, including health information. While we anticipate completing all work in five visits, we will plan with the resident a sixth visit and cancel it if not needed.

2.3.2.4.2 Health State, PHIM Practices and Process Analysis
During visit 2 we will follow the protocol developed for our 2002 Health@Home study (Moen & Brennan, 2005; Appendix 1) to capture PHIM practices. Two members of the vizHOME team will visit the home and conduct an interview, take photographs of all places, and undertake a process analysis. The interview guide is available in
Appendix 1 and will be modified to eliminate duplications after verification with the SHOW team who conducts the initial interviews during 2014. We anticipate that the second home visit will require 2 hours.

2.3.2.4.2.1 Task Process Analysis (Visits 2 and 3)
During the second home visit two members of the vizHOME team will meet the participant. The work system model of the SEIPS framework will be used as the conceptual guide to collect information on the following key processes:

1. medication management
2. self-assessment and monitoring of health status
3. management of health information.

For each key process, we will collect information on all elements of the work system (person, task, tools & technology, environment and organization). The visitor will record the occurrence of each of the tasks listed; they will not appraise the ease, quality or correctness of the performance. The data collection will rely primarily on a semi-structured interview of the patient and other household members. Draft questions for the interview guides are listed in Appendix 2. Whenever possible, the study participants will be asked to demonstrate task processes (“Can you show me how you do XXX?”). Therefore, interviews will be combined with observation of specific task performance in the household. This process will provide crucial aspects of understanding of the home for future analysis in the CAVE. The data collection process for this phase will be implemented on a tablet to allow ease of data capture and records. We will review the notes from visit 2 with the key informant. We will make modifications where necessary.

2.3.2.4.3 Preliminary Image Capture (Visit 3, 4, and 5 [and 6 if necessary])

We will ask the informant to give a tour of the home inspection. We will take still photos of key spaces; we considered using video capture but creating useful video images of homes where lighting may be problematic seemed ineffective; however, we will evaluate the need for video capture and review it with Carayon and Hoonakker during the training process. The process of home based assessment will be coordinated with the activities for the LIDAR image capture described below.

We estimate that it will take 4-8 hours over three to four visits to generate full digital 3D models of each house. A graduate student, under the supervision of Ponto and Tredinnick will conduct this part of the work. The models will be constructed in two separate sessions. In the first session, the larger rooms will be targeted. The second session will focus on acquiring data to bridge the previous scans together and to fill in any data holes in the scan. An elaboration of estimated scan times can be found in table 2 below.

<table>
<thead>
<tr>
<th>Scan</th>
<th>Average Number of Scans</th>
<th>Average Number of Rooms</th>
<th>Total Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Room (Living Room, Kitchen, Bedroom)</td>
<td>4</td>
<td>5</td>
<td>3.5 hours</td>
</tr>
<tr>
<td>Small Room (bath, large closet)</td>
<td>2</td>
<td>3</td>
<td>1.0 hours</td>
</tr>
<tr>
<td>Hallway</td>
<td>1</td>
<td>4</td>
<td>0.5 hours</td>
</tr>
<tr>
<td>Total / House</td>
<td>30</td>
<td>12</td>
<td>5.0 hours</td>
</tr>
</tbody>
</table>

Table 2: Estimation of time to complete scans in typical households of 12 unique spaces

Each visit will take from 60-180 minutes and include three data collection activities: interview, self-report, and observation by individuals or through photography (SLR) and point cloud capture (LiDAR).
2.3.2.4.3.1 Digital Model Creation: Data collection phase

While simple models of home environments are often created by architects and designers, these models lack the human element of the living environment (contrast upper photographs in Figure 2 with the artificial reconstruction in the lower images in Figure 2). Capturing the correct color of the wall or placement of a door does not capture the organic clutter of space. Details such as books scattered on a table, to a backpack left on a floor, are left out of simple diagrams due to the challenge in modeling them and their perceived lack of importance. Methods for automatic placement of objects also tend to produce results that feel artificial and inorganic as shown in Figure 3 below. For these reasons we have decided that it is important to generate high resolution models of the home environment using survey grade scanning techniques.

![Figure 2](image1.png)

**FIGURE 2** (Top) Actual home photos taken from Macdonald Realty Westmar (http://www.macrealty.com/)
(Bottom) Virtual home creations of the same unit by utherinteriors (http://www.utherinteriors.com/)

![Figure 3](image2.png)

**FIGURE 3**: Results of previous methods for automatic object placement. (A) Results of Cant and Langensiepen’s method to create a messy desk. (B) Germer and Schwarz method to create an untidy room. (C) An attempt by the algorithm in Howard et al. to create a “neat” placement of books on a shelf.

Terrestrial laser scanning (TLS) uses Light Detection And Ranging (LiDAR), a line-of-sight remote sensing technique, which rapidly determines the coordinates of objects relative to the scanner origin using either time of flight or phase shift information. High speed, phase-based terrestrial laser scanners compare phase shift between a modulated laser beam to determine distance to a target at close ranges. Time of flight based scanners measure the laser pulse travel time and the angle of return to determine the coordinates and are more suitable for larger ranges than the phase-based scanners. Various laser scanners are currently available with varying speeds (typically 1,000 to 1,000,000 points per second), maximum resolutions (typically 1mm to 100mm at 50 m), and accuracies (typically 3 to 10 mm at 100 m).

Most scanners concurrently photograph the scene to provide realistic color RGB values for each scan point or
they allow for images from a calibrated external camera to be mapped to the collected 3D data points. Scanners typically also provide an intensity measurement showing signal degradation, which can vary with material type. Because of the speed at which data can be collected, TLS has gained popularity in historical preservation projects for the 3D acquisition and subsequent modeling of buildings, sites, and works of art. Bernardini et al. (2002) used TLS to analyze Michelangelo’s Pieta statue. Dal Piaz et al. (2007) modeled and analyzed the stability of a historical structure using TLS. Guarnieri et al. (2005) also present the application of a TLS to a cultural heritage and structural analysis problem by creating 3D models and dynamic stress analysis using finite element analysis. Levoy et al. (2000) started the Digital Michelangelo Project to model and study Michelangelo’s David statue and has developed many useful tools for application of TLS to cultural heritage. While building rich models of famous artifacts has been explored, no one has yet attempted to create these types of rich models of everyday living places. For our purposes we require a LiDAR scanner than can fit into smaller spaces, and thus we have selected a Focus3D-S scanner. This model was selected as it is lightweight, mobile and easy to use. The Focus3D-S is capable of acquiring in spaces as small as 2’x2’ in full 3D with color.

A typical data acquisition workflow for laser scanning is shown in Figure 4 (left) above. In addition, Bernardini and Rushmeier (2002) discuss a typical processing pipeline for TLS data, focusing on acquisition. Scans need to be collected from several locations to obtain a complete model, and uniform alignment of the scans can be achieved through methods such as target-based, direct georeferencing (Figure 4, right) and software feature alignment.

Direct georeferencing (e.g. Scaioni, 2005) methods use objects as targets (Figure 4, right) that have known coordinates to align the scans together or surveying in control points where the scanner is set up. These coordinates can be obtained through GPS, Total Station, or other survey devices. Software registration determines the optimal alignment of a scan-based correlation of similar features in on neighboring scans to merge the scans together, and is comparable in accuracy to direct georeferencing for close range scanning (Alba, 2007). This can also be done by manually selecting corresponding points in adjacent scans to tie the scans together.

Once all of the scans have been registered, a single point cloud data set can be created. Since scans are commonly collected sequentially, i.e. at different times, different lighting conditions can cause artifacts to appear when combining and visualizing multiple scans. Olsen et al. demonstrated a means of correcting these kinds of artifacts using 2D image manipulation techniques (Figure 5), and we will apply that method here.
As LiDAR is line-of-sight, areas behind objects and the scanner will be in shadow. To fill in information for these shadowed regions, the scanner can be moved into new locations. For each setup of the LiDAR scanner, a point cloud is acquired and the point clouds are combined together to create a large dataset. Other technologies have been used to create point cloud data sets. Structure from motion uses relative camera movement to analyze objects’ movements in a scene to determine their depth. Unfortunately, this method is generally only able to produce sparse point clouds. Stereo image pairs have also have shown similar issues. Newer technologies, such as RGBD cameras like the Microsoft Kinect offer new possibilities for the generation of point cloud data. As the depth information from these devices is often low fidelity, the data generation requires a large amount of samples to average over. Additionally, relative positions of the Kinect must be determined to fill in data. This tends to lead to problems when acquiring objects of building size as relative inaccuracies tend to accumulate. This leads to diminished precision of the scan and problems when trying to scan large environments.

In each home we will use the LiDAR process to point clouds of the home; between each visit we will return to our laboratory, evaluate the data for integrity (that is, was the geometry fully captured) and realism (does the virtual image look like the photographs of the same house). We will proceed with the data capture/render phase sequentially for each house.

**2.3.2.4 Digital Model Creation: CAVE Rendering phase**

While vivid, full-color renderings of point cloud data can be accomplished in several ways, our plans to render this data in a CAVE has some distinct advantages. The CAVE offers a space to visualize the point cloud data not only in 3D but also at human scale. This means that designers and scientists can experience the dataset as opposed to simply view it on a screen. Also, the user in the CAVE environment can precisely tag locations in 3D. For example, as opposed to indicating that PHIM happens in a general area, a user can accurately represent the specific location in which a PHIM problem may occur. This also gives an easy method for the clustering of data in order to determine areas that have a high probability of influencing PHIM needs.

The point cloud data produces information for 3D positions in space. However, this data is sometimes challenging to work with for the purposes of visualization. Typical challenges of using point cloud datasets are that they are non-uniform (comes from an integration of different scans), can have some strongly biased errors (such as alignment errors during the data integration process), and do not natively have normal surface direction, thus making shading difficult. For these reasons, we plan to tessellate our point cloud data using the open source software MeshLab.

The tessellation process is comprised of five steps. First, the data is subsampled to make the data more regular and accelerate computations. To do this we will use Poisson Disk Sampling found in MeshLab. The second step is to reconstruct the normals of the data. We use the Poisson surface reconstruction found in MeshLab. The third step is to create a surface reconstruction. The normals computed in the previous step
enable a surface to be computed using the Poisson surface reconstruction found in MeshLab. As this method will tend to leave many small triangles, it is important to simplify the resulting mesh. We will use quadric simplification to remove 30% of the triangles that have been deemed unnecessary. As the fourth step, color from the original scan will be applied to the resulting model. Finally, we will clean up our resulting model to ensure redundant faces are removed.

Ponto and Tredinnick will lead this effort for converting point cloud to tessellated meshes. The tessellated mesh will enable virtual physics in the simulated environment. While the tessellating process is straightforward at a high level, there are many tweaks that will be necessary including manual touchups to spaces. All removed data will be filled in with adjacent background and texture colors. For these reasons, we expect the process to convert from a point cloud data set to a representative tessellated model to take between 10-40 hours depending on the conditions of the environment. Upon successful tessellation of the model, we will export the model from MeshLab to a model format suitable for rendering in the CAVE.

We will utilize the OpenSceneGraph open source graphics library for CAVE rendering. Home models will be named uniquely in a manner that does not reveal identity or location. Metadata will be attached to each home file to enumerate key features such as number of rooms and type of house, and unique aspects such as unusual color choices.

![Figure 6: Marking objects in virtual space (Left) Image taken from a user interacting with objects using the wand in a virtual kitchen in our CAVE (Right). TVCG demonstrating clustering technique for viewpoint extraction (Ponto et al, 2012)](image)

Participants in our studies will be able to mark objects or parts of the scene with a tag using the wand device, shown as the red line in Figure 6 above, left. The wand device produces a virtual beam in space that enables the user to label parts of the scene from a distance; we call this the “BeamCounter”. As users will likely want to label a region of space as opposed to a single point, we will treat the wand as a virtual camera or flashlight in the labeling process. This allows a user to quickly recall images of the labels generated in a scene. Furthermore, the process described in Ponto et al. 2012 TVCG enables the rapid clustering of views using the authors’ viewpoint similarity metric (Figure 6, right). This process will allow us to determine what object is designated as relevant to PHIM, and enables consensus to be determined between multiple users as to what objects and features shape PHIM needs. Both the final CAVE models and files storing the tagged “BeamCounter” data will be stored on our digital curation server as discussed in the Resources document. See Appendix 3 for an example of how the BeamCounter data is processed and presented.

To ensure that we have a sufficiently detailed 3D digital model of a home, we will compare the CAVE rendering of the model with the original SLR photographs taken during the second home visit. We will also compare specific areas of the 3D model with specific locations that our team took notes on during the task assessment, to ensure the specific locations recorded during task assessment contain sufficient visual detail for the next subprojects.

2.3.2.5 Variables
The variables for this phase are drawn from the SEIPS work systems model. A summary of the variables is provided below in Table 3; the specific variables from the SHOW team first assessment and the manner in which they map to the SEIPS model are provided in Appendix 1 and the entire SHOW variable set is provided in Appendix 4.
<table>
<thead>
<tr>
<th>Concept</th>
<th>Variables</th>
<th>How Measured</th>
<th>How Documented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual</td>
<td>Demographics, health status, Age, race &amp; ethnicity, insurance status, income as a % of poverty line, literacy</td>
<td>Self-report, interview</td>
<td>SHOW survey</td>
</tr>
<tr>
<td>Task</td>
<td>Medication management, monitoring and management of health information</td>
<td>Observation, interview</td>
<td>1. Annotated Flow charts</td>
</tr>
<tr>
<td>Tools and Technology</td>
<td>Devices used for PHIM (e.g. glucometer, insulin pump)</td>
<td>Interview</td>
<td>1. Survey 2. Photographs</td>
</tr>
<tr>
<td>Organization</td>
<td>Policies that guide PHIM</td>
<td>Interview</td>
<td>Survey</td>
</tr>
<tr>
<td>Environment</td>
<td>Spaces where PHIM occurs and objects that are used to evoke or manage PHIM</td>
<td>Observation, LiDAR, image capture, drawings</td>
<td>1. point cloud data 2. photographs 3. layout drawings</td>
</tr>
</tbody>
</table>

Table 3. Summary of variables drawn from the SIEPS Model.
2.3.2.6 Data Reduction and preparation

The SHOW team will summarize and prepare a file of all interview data from the first home visit. They will also provide the index variables that allow connecting the 20 cases from this study with that of the larger SHOW sample collected concurrently. Dr. Casper will work with Tredinnick to oversee the creation of the data files in the Lab Key resource in our server system (see Resources & Environment).

One flow chart will be created for each task within each household. We will create 60 task structures. These will be stored in computer files as .pdf documents that can be annotated by team members. The home assessment data reduction and preparation process will occur as follows:

1. data cleaning and verification
2. descriptive statistics on demographics and background information
3. descriptive statistics on household environments, task processes, and task processes/environment

2.3.2.7 Data Analysis and Interpretation

Guided by Carayon and Hoonakker, we will use the interview and observation data (see Appendix 1) to produce process maps that describe the physical and temporal organization of task processes performed by the patient and other household members. We have used process mapping as a data analysis tool in several research projects, including process maps of the outpatient surgery process (Carayon, Schultz, & Hundt, 2004; Schultz, Carayon, Hundt, & Springman, 2005). We will create individual process maps for each household for each of the three information tasks. The columns will represent different locations of where tasks are performed (e.g., kitchen, living room, bedroom) [environment; physical organization]; the rows will describe the various phases of the process [temporal organization]. The cells of the process maps will include information on who performs what tasks with which information tools. The information tools will be represented using various flow charting icons (See Appendix 2). For each key process we will have a total of 20 maps.

Because we expect that the key processes will involve collaboration between the patient and other household members, we will probe for the role networks and task interdependence to represent the information flow among all of these people. The patient will be at the center of the role network. Other members of the household (who will not be interviewed directly) will be connected to the patient; these arrows will be used to describe the specific information that flows between the patient and a specific household member. We will create separate role networks for each of the three key processes for each of the twenty homes.

At the end of the households assessments we will have an electronic profile of each home including three sets of data about the house and the RU: descriptions of home work system, descriptions of context (text, still photos and drawings), and a digital 3D visual-spatial data file of the house. The data analysis process will (1) apply the Health@Home model to begin to characterize information management practices by purpose and location and (2) determine if there are differences of how similar tasks are done in different households and (3) review images to reconstruct task activities.

There are few known strategies to compare differences in task performance by site. Provencher et al (2012) focused on a gestalt assessment of the visual appraisal of differences between two environments as a way to compare two sites, and then measured the time to complete tasks. Given the complexity of household environments, absolute measurement of the distance between two objects, the presence or absence of gross hazards such as door mantles or an enumeration of the presence or absence of objects, seems either excessive or distracting. Yet gross differences, such as counts of the number of rooms or enumeration of the rooms in which activities occur also seem inappropriate. We propose to use a constant comparative method to first enumerate the task-environment features, and then repeatedly and recursively review the materials with a goal of parsimony and explicitness. We will follow the process comparison method developed by one of Brennan’s students (Ozkaynak & Brennan, 2011) to construct a similarity index of each process, allowing us to determine if tasks are done differently in different contexts. Brennan and Casper will direct this part of the analysis. The first step has two products: 1) an enumeration of 3 tasks as they occur in each environment and (2) a complete set of images and LiDAR-captured point cloud data from each household.
2.3.3 Information Requirements Determination (Brennan, Ponto, Nathan-Roberts, Casper)

2.3.3.1 Purpose

This third subproject will result in an enumeration of a proposed set of household context indicators that influence PHIM. This enumeration will form the basis of the experimental validation efforts in subprojects 3 and 4.

2.3.3.2 Setting and Sample

The setting is the Living Environments Laboratory at the Wisconsin Institute for Discovery. The sample is the virtual renderings of the 20 households created during the first subproject (2.3.2.4.4).

2.3.3.3 Sampling Plan

Each virtual rendering of a real house (n = 20) will be reviewed by three members of our investigation team. We have six professionals (Brennan, Ponto, Casper, Nathan-Roberts, Carayon, Hoonakker) with different but related expertise in health care, home care, technology design and human factors engineering. Each team member will view 10 virtual houses (15 hours in total) so each virtual house will be viewed by at least 3 people. We estimate that this effort will take at least 6 months, and can be completed in Quarters 3 and 4 of year 2.

2.3.3.4 Procedure

The protocol will be established by the team, and Casper will develop a training procedure to ensure that each team member observes consistently. We have available a prototype virtual house structure, created during the original set up of the LEL CAVE as a proof of concept, to serve as a training, practice, and calibration site.

Virtual home assessments will be done by each of the six team members independently but concurrently in design workshops lasting two days each. Each member will assess 10 of the 20 virtual houses. Each assessment will follow the same protocol:

1. Familiarization routine: enter the space, navigate by walking through visible areas, use joystick to navigate through the entire space, speaking aloud any key observations which can be analyzed offline.

2. Using the task process summary created in subproject #1, walk through the virtual space using the task process summary as a map or guide. Make note of the features of the house that appear to be relevant to the task. Relevance is a subjective judgment, based largely on the affordances provided by feature.
   a. We will employ a BeamCounter to make notation. To do so involves pointing a VR interaction device, called a Wand, at the household feature that appears relevant to the tasks. The beam results in a tag being placed as a record of a point in 3-dimensional space where an object resides. Two types of tags will be possible: one that indicates a household feature that seems to relate to health information management (e.g. a calendar that reminds a resident when to go to a clinic visit) and one that identifies a specific health information management tool. This requires professional judgment, and may have a high level of variability. The process results in a collection of virtual sticky notes
   b. Repeat the task for 10 virtual households, 3 tasks in each house.

3. Review the tags and remove redundancies

4. For each virtual house, bring the observers together to review tags, with a goal of generating consensus. Key consensus building rules include proximity, location and affordance
2.3.3.5 Variables

This information requirements subproject has input variables (households, rooms, objects in rooms) and output variables (objects noted as relevant to information management). We will identify the location of objects determined as affordances to PHIM by team members through a process we have developed called BeamCounter.

Each participant will generate a series of labels using the “BeamCounter”. A BeamCount results when the participant points the input/navigation device (the Wand) at an object or space. A record is incremented each time a point or location becomes the focus. We can then use the procedure described in 2.3.2.4.4.2 to create overlapping beams. These labels can be rapidly compared and contrasted using the viewpoint similarity metric found in Ponto et al. TVCG 2012. This algorithm will determine how much of the scene is common between two captured beams (conceptually how much of all of the user's individual beams overlap). Using this analysis, consensus areas of the scene can be computationally determined.

2.3.3.6 Data Reduction and preparation

We will complete this exercise and have 3 assessments of 20 homes, each with 3 tasks embedded in the homes. We will create matrices and other visual displays of the households and the points in the households that were identified as relevant to information processing. We will also have an enumeration of all of the elements in the house indicated as relevant to health information processing. The SEIPS model is important here because it will provide a structure for assigning the elements of the house, and allow us to focus explicitly on the physical aspects. In this subproject, we have disentangled the person/environment and task-environment interaction, and will be ready to create a candidate list of elements in the household that influence health information management. By referring to the flow charts of the three information tasks, we will be able to appraise the consistency of the PHIM and the household indicators that may influence it.

2.3.3.7 Data Analysis and Interpretation

We will produce an enumeration of the elements of the household that may be considered stimulators, enablers or barriers to health information management. These will become the list of features that influence health information management. We will also complete this phase with a completely marked up virtual home with explicit 3D position information of all of the contextual features that may influence PHIM.

2.3.4 Subproject 3: Requirements Validation [Top Down] (Nathan-Roberts, Casper, Ponto)

In Subproject 3 we will identify the most important household features that influence PHIM. We will use the dual process research methodology. The dual process research methodology states that to understand design problems, researchers should address them from both a top-down process of discovering the major design factors by observation, and a bottom-up process of testing the specific effects of each factor on design and each other, informing future top-down research (Liu, 2003). One of the primary goals of top-down research is to observe user choices to intuit the independent variables and understand the range of levels of those variables so that more detailed research can take place. Bottom-up research (Subproject 4) uses the findings from top-down research as a guide for variables and problems, and goes further to explicitly test theories and creates experiments that have not naturally occurred. Using the dual process research methodology as a framework for this research, this work is divided into two components: initially determining the key theories and levels to study (Subproject 3), followed by performing controlled studies manipulating the most important variables to better understand their impact on personal health information management (Subproject 4).

A top down approach accelerates the definition of the most salient features of the home likely to influence PHIM by systematically exposing participants to household environments and prompting the participants with a set of PHIM tasks. The respondents are then asked to indicate features of the home space that engage or interfere with individuals completing PHIM. Once the top-down subproject is completed, the strength of the
The effect of each variable on personal health information management, and the inter-relation between the key variables can be tested using bottom-up Requirements Experimental Manipulation (Subproject 4).

2.3.4.1 Purpose

The specific aim of Top-Down Requirements Determination research component is to validate or eliminate factors identified in the home environment in the Requirements Determination phase that influence PHIM. The strategy we are undertaking provides a measure of generalizability. When a home is surveyed, the results are confounded by the resident of that home because only the current resident’s current habits are studied. To understand the home environment further it is therefore important for researchers to remove the home-resident interaction by looking at how other people would use the same environment. This experiment importantly decouples the home-resident interaction by systematically testing how other potential residents would use the same space.

2.3.4.2 Setting and Sample

This Subproject will occur in the CAVE. The sample for the Requirements Validation studies is adults with a self-reported diagnosis of diabetes. We propose to recruit our entire sample using the sample frame that exists of the participants in the SHOW database who have self-identified with diabetes and have indicated a willingness to be contacted for participation in later studies. The inclusion criteria are age over 25 and self-reported diagnosis of diabetes. During the first three years of the SHOW project almost 1000 people were enrolled each year; about 10% of those recruited each year self-identified that they had diabetes. Thus we believe that there are 300 eligible people in the sampling frame and we can expect to recruit between 10 and 20% of these per year. We are confident that we will reach our sampling goal in year 3. We will not explicitly stratify to target recruitment of people at specific disease stages because the information management components of diabetes self-management are relatively consistent, even though the demand may fluctuate over the natural course of the disease. The researchers will make every reasonable effort to recruit and select a set of participants with a balance of disease states. Participants will be compensated for their time ($25 per hour plus travel and meals; maximum compensation per person $112.50).

2.3.4.3 Sampling Plan

Participants will be recruited through a direct solicitation of people in the SHOW database who have self-identified as having diabetes. An electronic or paper letter will be sent to those in the SHOW database who have been self-identified with diabetes informing them of the study and requesting the opportunity to contact them about participating. We will also ask the SHOW data collectors who are active between Q4 of year 2 and Q3 of year 3 of this project to provide a paper flyer to any new participant in SHOW who meets the inclusion criteria. The target sample size is twenty participants. Previous research has shown that participant groups of this size are sufficient for determining the variables of interest in complex, multi-variable design problems (Nathan-Roberts & Liu, 2010; Nathan-Roberts, & Liu, 2012; Nathan-Roberts, Kelly, & Liu, 2011). Recruitment will continue on an ongoing basis in years two and three to ensure enough participants can be found.

2.3.4.4 Procedure

Dr. Casper will contact SHOW participants willing to be in this study via phone or email and will explain the study. If the person agrees, they will be scheduled for an appointment in the Living Environment Laboratory (LEL) at the Wisconsin Institute of Discovery (WID). Upon arrival at the LEL, Casper will review the study protocol, give the participant a 10 min tour of the facility, and solicit consent. When the participant consents the study will begin. This non-experimental protocol will consist of three parts; an introduction, the main data collection, and a short debrief. The procedure will focus on having participants walk through the virtual houses
and explain which room(s) of the virtual homes these new participants would use to manage specific care tasks (identified earlier) and why. Training for the study will include orientation to the CAVE and the special glasses that must be worn in the CAVE, and how to use the Wand for BeamCounting and a colloquial version of the three health information management tasks documented in the first step. We anticipate that the training will take 15 minutes.

We will follow the same procedure for each of four virtual homes. In each home participants will tour the home and answer questions in each room about whether or not they would use that room for managing their care and why (15 minutes per home; total of 60 minutes). Participants will be permitted to spend up to 30 minutes per home if necessary (thus placing a upper bound on the minutes of CAVE exposure to 120 minutes). The study by Kennedy et al. on how simulator sickness is manifest in virtual environments, gives us confidence that these time intervals are acceptable (Kennedy, 2010). Nathan-Roberts, Casper and a graduate student, overseen by Brennan will conduct this phase, including accompanying the participant, verbally relaying the questions and recording the responses. Individuals will be encouraged to take breaks as needed, and if we find the experience fatiguing we will modify the proposal. We have noted that ambulating in virtual space is less stressful than using the joy-stick on the wand to travel far distances. Thus we will minimize the amount of navigation using the joystick.

We will, with the guidance of Carayon and Hoonakker, develop a set of questions to solicit the participants’ assessment of the impact of household features on PHIM as organized by the SEIPS model features including, for example:

1. Which processes would you complete in this room and why (TASK)?
2. Which parts of the room would be used for each process (ENVIRONMENT)?
3. What features in this space might assist a person in doing this process here? (marked with BeamCounter) (TASK/ENVIRONMENT)
4. What features of this space hinder its use for each process? (marked with BeamCounter) (TASK/ENVIRONMENT)
5. Are there family living patterns, personal beliefs or cultural norms that may help or hinder the use of this space for each process (INDIVIDUAL, ORGANIZATION)?

After completing the navigation and questions for each of the four virtual homes, participants will complete a debrief questionnaire about the effect of context. We will thank the person and provide them a payment at the end of the process.

We will randomize the assignment of the sequence order of viewing of the 10 households (the number of full and usable digital files of virtual houses that we are confident to get) to the 20 participants such that each virtual house is viewed 8 times and each participant views 4 houses. Within each of the four houses viewed by each individual the participant will walk through three intensive information management practices (gleaned from Step 1). Thus we will have 12 sets of judgments per participant.

2.3.4.5 Variables

The independent variables will be home (10 of the homes captured will be used) and process (3 processes related to diabetes will be used: medication management, self-assessment and monitoring of health status, and management of health information).

There will be three kinds of dependent variables: the dependent variables about room selection and use, 3D data generated by the participants using the wand (BeamCounter technique) about the objects in the spaces, and qualitative subjective feedback about the spaces, and their subjective feedback about needs and preferences. The dependent variables about room selection and use will be quantitative selection of which room(s) are selected to be used for each process in each home. The 3D data dependent variables will be the aspects of the spaces that help and hinder each process as highlighted by the user. The subjective feedback dependent variables will be the answers to the debriefing questionnaires.
2.3.4.6 Data Reduction and Preparation

The quantitative dependent variables of room selection and use will be collected into a table showing participants choices in each room. BeamCounter data will be collected for each participant and stored on secure lab servers. The subjective data from participants will be collected in NVivo software for qualitative analysis.

2.3.4.7 Data Analysis and Interpretation

The quantitative dependent variable data about room selection and use will be analyzed using frequency counting and cluster analysis to learn more about how participants other than the home-resident would use the room. The subjective feedback will be analyzed using NVivo to provide support and understanding to the quantitative dependent variables about room selection and use as well as the BeamCounter data of the environment.

As described previously, each participant will generate a series of tags or labels using the “BeamCounter”. These labels can be rapidly compared and contrasted using the viewpoint similarity metric found in Ponto et al. TVCG 2012. This algorithm will determine how much of the scene is common between two captured beams (conceptually how much of all of the user’s individual beams overlap). The unit of analysis is a volumetric appraisal of a specific space. Using this analysis, consensus areas of all 20 appraisals on every scene can be computationally determined. This can also be visualized in the environment as a heatmap, where brightly lit areas represent areas of the scene with mutual agreement among users. From this, it can be determined what features of an environment are deemed most important to PHIM needs as a consensus of the overlapping beam locations. Should we find that there is no consensus we would conclude that the space itself rather than specific points exerts significant influence on the PHIM.

At the end of this experiment we will have the set of household context features that identified with the greatest influence (positive and negative) of people’s PHIM. We will also have at least two levels of each feature (e.g. present, absent).

This set of variables and the levels of those variables will be analyzed within the context of the findings of Subproject 2, and Subproject 1. The findings of subproject 1, especially the home work system analysis will be crucial in providing a larger framework for understanding the findings of Subprojects 2 and 3. Through the understanding of the entire work system of the resident, including the interactions between home environment and the other aspects, such as tools they use, we will better understand which context variables should be manipulated in Subproject 4. For example, understanding if the home resident checks their medications in a different location because the pill containers are too tall to fit in their medicine cabinet, will allow us to make more relevant comparisons than had we performed Subprojects 2 and 3 alone.

A set of variables and levels of those variables will be generated from a synthesis of the findings of the home visits, Subproject 2, and Subproject 3. These household context features will form the core set of information requirements determinants from the physical aspects of the house, and will be manipulated in a factorial experiment in Subproject 4.

2.3.5 Subproject 4: Requirements Experimental Manipulation (Bottom-up)

2.3.5.1 Purpose

The specific aim of this portion of the project is to better understand the variables previously found to affect PHIM. The previous experiments used the homes to learn about the impact of environment on PHIM. This experiment will, in a controlled manner, manipulate the variables that the previous experiments found to look
more closely at people's sensitivity to these variables. This allows researchers to gain more insight than would be available only through home visits or modeling homes.

The experiment will manipulate the physical context components found previously to have the largest effect on PHIM in a controlled manner to look at the sensitivity of PHIM to each of these variables. Participants will be shown pairs of rooms (i.e., two kitchens) and be asked to pick in which space they would complete each of the three processes.

2.3.5.2 Setting and Sample

The experimental part of this Subproject will occur in the CAVE in the Living Environments Laboratory at the University of Wisconsin-Madison. Participants will be recruited for this experiment who, in the SHOW surveys, self-reported a diagnosis of diabetes and indicated a willingness to be contacted for future studies. Participants will be recruited in the same manner as the previous experiment. The researchers will make every reasonable effort to recruit and select a set of participants with a balance of disease states. Participants in Subproject 4 will be compensated for their time for a total of $112.50.

We plan to recruit 60 participants for this Information Requirements experiment. The sample size calculation is based on the primary outcome variable of selection of one room over another for each process. Preliminary power analysis showed that 60 participants will result in 80% power to detect a 2.2% difference between variable levels with a standard deviation +/- 3.0%. Previous design experiments show that using a top-down followed by a bottom-up approach can easily create differences in preferences this large or larger, and that this population size will be large enough to potentially benefit from Principal Component Analysis (Nathan-Roberts, & Liu, 2010).

2.3.5.3 Sampling Plan

Recruiting participants will follow the sampling strategy and inclusion criteria as noted in Subproject 3. Participants in the SHOW project who indicated a willingness to participate in the future research and have self-identified as having diabetes will be recruited via email or postal mail. We estimate recruiting 1-2 people a week and should have the completed sample by month 42.

2.3.5.4 Procedure

Similar to the previous experiment there will be three parts to the data collection component: introduction, data collection, and debrief. In the introduction portion participants will be given an overview, informed of their right to discontinue at any time, consent to participate, and then train for the experiment. Participants will then proceed into the CAVE for the main data collection portion of the experiment.

In the CAVE, participants will complete the same task 10 times in different pairs of rooms. Participants will be asked to compare two rooms from different homes (e.g., two kitchens). In each comparison, participants will be asked to choose in which room of the pair they would prefer to perform each of the three tasks. These forced-choice paired-comparisons will be between two virtual rooms, each from different virtual homes, that have been manipulated to be the same except for the one variable that is of interest. The rooms will be manipulated to have the variables found to have the highest impact be the same. The exact variables will be identified as a result of the previous Subprojects so we cannot describe the exact example at this time.

A plausible example would be as follows, the participants will explore two kitchens from real homes which have been manipulated to have the refrigerator closer or farther from a countertop, but also have been manipulated to both have a calendar hanging on a wall where the entire family can see upcoming doctor's appointments or other scheduled care. Participants will then choose which room they would perform each of the 3 self-management tasks in. They will repeat this forced-choice comparison for a 10 pairs of homes, each being controlled for variance along the variables of interest to PHIM in the previous Subprojects. Several types of like-room pairs will be tested, such as kitchens, bedrooms, and living rooms.
After completing the questions for each home, participants will complete a debrief questionnaire, and answer questions regarding the effect of context.

2.3.5.5 Variables

The independent variables tested in this experiment will be the 10 variables that had the largest impact on PHIM in the top down validation process. Each variable will have two levels that are determined by the mean and standard deviation of the homes that were sampled. For each independent variable, one level that is above and one that is below the mean of what was found in the surveyed homes is what will be used. For example, if we find that distance between a counter and the refrigerator impacts PHIM performance, the two levels will be one standard deviation closer than the mean found in the homes visited, and the other level would be one standard deviation further away than the mean. It is impossible to know exactly which aspects of the context will have the largest impact on PHIM at this point, it is therefore necessary to complete this experiment after the previous experiments have been completed.

The dependent variables in this experiment will be if the room is selected for each process, which level of each independent variable is selected, and subjective feedback. The participants will be broken into three groups, with each group experiencing the same experiments in home pairings to control for the effect of room aesthetics (furniture quality, wall color, etc.).

2.3.5.6 Data Reduction and preparation

The quantitative dependent variables of room selection and use will be collected into a table showing participants choices in each room. The subjective data from participants will be collected in NVivo software for qualitative analysis.

2.3.5.7 Data Analysis and Interpretation

Principal Component Analysis, as well as ANOVA models will be used to determine the impact of each of the independent variables as well as the level that is most likely to help participants with their health information management. The qualitative data will be used to better understand our results as well as to inform future work. The SEIPS model will be used as a framework to connect the quantitative and qualitative findings in Subproject 4 with the previous Subprojects.

2.3.6 Subproject 5: Generalization of the Assessment of the Context of the Home Environment (ACHE) Inventory

2.3.6.1 Purpose

The four preceding Subprojects will yield an enumeration of the factors (no fewer than 5, no more than 10) in the interior household environment likely to influence PHIM. Notwithstanding the importance of social factors, task characteristics and available tools and technologies, we continue to focus on the characteristics of the internal physical environment. The next logical step is to document the manner in which the factors gleaned from the 20 households studied intensively in the virtual replicates here are manifest in a larger array of households. The purpose of this exercise is to determine the generalizability of the feature set discovered through the first four subprojects.

2.3.6.2 Setting & Sample

The setting for the Generalization study is the urban and rural region of central Wisconsin. We will sample 200 households in the urban and rural area of central Wisconsin. The sampling frame will be that employed by the SHOW team during 2017-2018. The SHOW sampling frame (Nieto et al., 2010) employs a two-stage cluster sampling to extract a subset of Wisconsin Census Block Groups (CBGs) then apply simple random sampling to select households from each CBG. They recruit approximately 800-1,000 adult participants (21-74 years old).
Each year. Every household is geocoded for linkage with existing contextual data including community level measures of the social and physical environment; local neighborhood characteristics are also recorded using an audit tool. Because we intend to create a nominal enumeration and do not intend to create a summative index we will use heuristics to determine the sample size. Based on Nunnally (1978) we will seek 20 instances per item in the ACHE, and seek a sample of 200.

2.3.6.3 Sampling Plan

We will purposively select 50 respondents from each of the four housing types to achieve a sample of 200. We will sample sequentially with replacement until all sample participants are recruited. The SHOW team faces challenges recruiting from apartment dwellings (due to difficulty in accessing the household directly because of security doors); should they experience difficulty recruiting a sufficient sample for this study, we will modify the sampling plan if warranted by evidence from the previous work that determines whether housing type exerts a systematic influence on the interior environment characteristics that effect PHIM.
2.3.6.4 Procedure
We have an agreement from the SHOW staff (submitted) that they will include the ACHE inventory developed through the first four phases of this study in the interview packet for the home survey. SHOW staff will administer the inventory as part of the battery of in-house assessments completed as part of the routine SHOW assessment. The SHOW team will return to the vizHOME team a data file with the ACHE inventory data and the household data, including characterization of the census block and community where the house is located. We anticipate that this will be completed during months 42-54 of the proposed project.

2.3.6.5 Variables
The Assessment of the Context of Household Environments (ACHE) is the instrument that will be tested in this phase of the project. While the exact configuration of the ACHE awaits the conduct of this series of Subprojects, we anticipate that it will be an enumeration of the number of rooms, household objects, arrangements of household objects, spaces or distance between spaces. Explicating the task process analysis with a focus on the information management components in the virtual home environments will reveal the extent to which the environmental context exerts a differential effect depending on the task at hand. It is likely that the dimensions of this inventory will include objects, proximity, privacy, communication aligned with preferred mode of the home-dweller. See a sample ACHE Inventory in Appendix 5.

2.3.6.6 Data reduction and preparation
We will create charts and tables of the inventory responses, examining for patterns and coherence as recommended. We will use exploratory data analysis strategies to examine for variability in the factors. We will also look for co-occurring patterns. We propose to re-visit the 20 virtual households, using the BeamCounter again to denote space configurations that occur most often, those that co-occur, and those that occur rarely. Through iterative discussion we will determine whether the task process/context patterns that we observed in the 20 virtual homes is borne out with the observations from 200 participants in Subproject 5.

2.3.6.7 Data analysis and interpretation
The purpose of the data analysis is to provide an appraisal of the extent of variability in the factors across households, and to provide additionally evidence in support of or refuting the original research questions. The large sample generalization will allow validation that the patterns found in the intensive exploration of the 20 virtual households holds in a more general environment. We will rely largely on descriptive statistics and correlations.
2.4 Limitations
The focus of this study is on the aspect of the home interiors most likely to shape PHIM: the spaces and the objects within the spaces. The impact of other aspects of the physical environment, including temperature, sound, humidity, etc, awaits attention in future studies (e.g. examining the impact of TV sound on distraction). Our project provides a single point in time study of the environmental context; future work should address the complex interplay of how residents adapt to their environments. Finally, we explored only a subset of information needs and PHIM strategies; future work should address others such as retrieving information in an emergency and recognizing and detecting early signs of disruptive behavior.

2.5 Personnel
The project will be led by Patricia Flatley Brennan, who is a nurse and an industrial engineer. Brennan has over 25 years’ experience in the design, deployment and evaluation of computer technologies for home care. Recognized as a leader in patient-focused computing, Brennan recently led the development of guidelines applying human factors to the use of technology in the home (NRC, 2012). She has marshaled a team of experts in human factors engineering, evaluation research, and virtual reality to come together for this project. To reach as broad a community participation as possible, Brennan will be partnering for the first time with the Survey of the Health of Wisconsin (SHOW) team; this partnership will leverage the outreach and public good will held by SHOW as well as provide access to a network of community engagement experts.

2.6 Project Administration
Brennan led the development of the proposal and is responsible for overall direction of the project, and will be responsible for the three phases: home assessment, virtual home recreation, and requirements elicitation. She will conduct quarterly meetings with lead investigators as well as weekly meetings with operations staff (Casper, Ponto, Nathan-Roberts, Tredinnick, RAs) Brennan will also oversee Subproject 4 and 5.

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Launch

1. Home Assessment & Virtual Rendering

2. Requirements Definition

3. Requirements Validation: Top Down

4. Requirements Experimental Manipulation: Bottom up

5. Generalization of the ACHE

Dissemination

Casper, a PhD prepared health services researcher, will have day-to-day operations responsibility for the project. Brennan and Casper have worked together for over a decade on all of the major home care and
patient-oriented computing projects conducted in this lab. Casper has particular strength in home assessments and in managing remote and on-site interdisciplinary teams. Casper will have primary responsibility for integration with the SHOW team, and for assuring the conduct of the validation subproject. We considered reducing this position to a ½ time position and adding additional student support; however, it has been the experience of our group that day-to-day professional staff leadership is essential to ensuring data integrity, on-time performance of an experiment, and effective external relations. Our tradition has been to engage student participants, far beyond those identified in a proposal, on a project; we have also had success in engaging other investigators in spin-off activities of our large projects. Such a level of engagement requires a high-level project director. Ponto will oversee all technology implementation activities and Nathan-Roberts, with the support and supervision of Brennan, will be responsible for design exercises (Subprojects 3 and 4)

2.7 Dissemination

We plan to employ traditional dissemination strategies in the professional peer-reviewed mechanisms. Additionally we will employ novel dissemination strategies to ensure that the findings we glean enter the design process in a timely manner. We propose to use our web sites (www.son.wisc.edu; www.discovery.wisc.edu/lel) to invite designers to use the CAVE as a product planning and testing space. We also propose to put our reconstructed home models online to enable designers, students, and researchers to study and explore these household environments. We propose to use our current outreach efforts to researchers and the general public to examine the households and understand the placement of key indicators. We will link our ACHE inventory to the existing designer’s guides (e.g. healthit.ahrq.gov) to provide more explicit guidance of what features in the household contribute to health information management. See letters of support from the School of Nursing and the Wisconsin Institute for Discovery.
REFERENCES


