Development and Effectiveness Evaluation of a Virtualized Reality Telerehabilitation System for Accessibility Analysis of Built Environment

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The specific aims of this work are as follow: 1) to develop the Virtual Reality Telerehabilitation System (VRTS) which can enable clinicians to assess the wheelchair accessibility of users' homes from a remote location. 2) to investigate the effectiveness of this new accessibility assessment system using Virtual Reality technology and the Telerehabilitation concept as compared to a conventional assessment method.

The development of VRTS begins with reliability analysis via data accuracy analysis, camera usability analysis, and a field feasibility test study, and it evolves into the development of algorithms to acquire information and images, make 3D models, and analyze accessibility in virtual environments. A guideline for taking good pictures and a survey form have been developed to collect images and descriptive information for the target environment.

A field evaluation is proposed to test whether this new system is comparable to the traditional method of accessibility assessment. In cooperation with a regional architectural firm, three clients requesting an evaluation of accessibility of their houses will be recruited. A target house will be assessed via the Conventional In Person (CIP) method by an architect of the firm and via the VRTS by another architect. A descriptive analysis will be performed to compare the VRTS assessment with the CIP onsite evaluation.

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PREFACE

I would like to thank my committee members Dr. Brienza, Architect Lynch, Dr. Cooper, Dr. Boninger, Dr. Simpson for their advice and insightful guidance throughout my study. Especially, I'm so grateful to Dr. Brienza, who has supported me in so many ways and Bob Lynch for his expertise in the accessibility assessment and architectural services.

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OVR program, UCP caregiver program, University's Disability Services, ADA, and disability right activists that made the current accessible environment.

If there was not one of them, I couldn't be here now.

Lastly, I would like to thank The Lord, Jesus Christ, for leading me thus far.

CHAPTER 1: INTRODUCTION

1.1 Statement of the Problem

According to the Census Bureau's Survey of Income and Program Participation, the number of wheelchair users aged 18 years and over in 1999 was estimated at more than 2.3 million in the U.S. [1] An important trend in usage of wheeled mobility devices is that the number of people using wheelchairs is increasing yearly; thus the demand for wheelchairs is likely to continue to grow in the foreseeable future [2].

For any given limitation in function, the amount of disability an individual experiences will depend on the quality of the social and physical environment [3]. Consideration of the built environment is especially critical for wheelchair users, given the potential limitations that environment can impose. The most effective rehabilitation outcomes are realized when programs consider both functional restoration and environmental modification [3].Most importantly, for mobility devices to be used effectively, the environments in which they are used must be physically accessible [4]. The 1995 American Housing Survey (AHS) asked whether members of households had permanent physical activity limitations and, if so, whether home modifications had been performed. Based on the survey, approximately 5.1 million (57.4 percent) of the households in which a member had an activity limitation had no home modification [5].

The home environment introduces new considerations related primarily to safety and to the performance of basic living activities [6]. Home modification has come to be recognized as an important intervention strategy to manage health care conditions, maintain or improve functioning, ensure safety, and reduce the wheelchair user's dependency on others. [7]. Effective home modification requires consultation with skilled professionals capable of assessing the home environment and identifying changes necessary to meet the wheelchair user's needs. While there are many building and remodeling contractors able to perform the modifications, the availability of skilled professionals with experience in home modifications for accessibility is limited. Providing services in rural areas is particularly difficult. Such service requires lengthy travel times that increase cost and consume the limited time of skilled professionals. Even if a specialist is willing to travel a long distance, travel cost is too high relative to the fee for modification. And even a specialist couldn't accurately assess the environment's accessibility without visiting the site.

A system that enables accurate remote assessments would be an important tool to improve our ability to perform home assessments more easily and at decreased cost. Therefore, this study addressed the development of a remote accessibility assessment system using the concept of telerehabilitation and the virtual reality technologies and their effects. This system used commercial software to construct 3D virtualized environments from photographs. Custom screening algorithms and instruments for analyzing accessibility have been developed.

Characteristics of the camera and the 3D reconstruction program significantly affect the overall reliability of the system. In this study, we performed two reliability analyses on the hardware and software components: 1) Verification that the commercial software, Photomodeler Pro, can construct sufficiently accurate 3D models by analyzing the accuracy of the dimensional measurements in the virtualized environment; 2) comparison of dimensional measurements with four camera types. Based on these two analyses, we were able to specify a consumer level digital camera and the Photomodeler Pro software for this system. As the third phase, we tested the system in an actual environment to evaluate its ability to assess the accessibility of a wheelchair user's typical built environment. This feasibility test resulted in an accurate accessibility assessment, thus validating our system.

Through these pilot studies, algorithms for constructing 3D models of wheelchair users' home environments and for assessing the environments' accessibility were developed, including the development of several new tools, such as a guidelines book on how to take pictures, a survey form, a measurement form, and a evaluation form. As the last phase of this study, we evaluated the developed system's capability, as compared to that of the CIP method, in assessing the accessibility of the wheelchair user's built environment.

1.2 Specific Aims

In this study, a new and alternative solution was developed—the Virtual Reality Telerehabilitation System (VRTS)—which uses accessibility screening algorithms to evaluate wheelchair accessibility of an individual's physical environment, taking advantage of state-of-the-art technologies of digital imaging, 3D reconstruction, and photogrammetry. The study includes the development of algorithms that will standardize and simplify procedures for assessing the accessibility of the home environment, using the above technologies. Our solution includes the development of several new tools, such as a guidelines book on how to take photos, a survey form, a measurement form, and an evaluation form. The study has developed a comprehensive procedure for assessment of the home environment's accessibility, using telerehabilitation and virtual reality technology. The study explored the most effective means of constructing 3D models from 2D photos of an interior architectural environment, including how to take efficient photos and how to effectively manipulate the commercial software.

We evaluated our newly developed method by examining agreement between the VRTS method and the Conventional In Person (CIP) method for assessing the accessibility of a wheelchair user's home. Specific aims of this study are as follow:

1) Investigate the system's capability for accuracy in modeling interior environments.
2) Identify an appropriate camera set for the system.
3) Develop algorithms for constructing 3D models of wheelchair users' home environments and for assessing the accessibility of those environments, including the development of several new tools, such as a guidelines book on how to take efficient pictures, a survey form, and an evaluation form.
4) Assess the level of agreement between the CIP method and the VRTS method in evaluating the accessibility of a wheelchair user's home environment.

1.3 Significance

Our VRTS is designed to evaluate the accessibility of physical environments of wheelchair users. The VRTS takes advantage of state-of-the-art digital imaging, 3D modeling, and photogrammetry technologies. Accuracy is a critical concern in the virtualized environment [38] and usability is a primary concern for the telerehabilitation system [71]. Accuracy and usability are important for developing a successful system. The current study was initiated to analyze the reliability of candidate technologies

Field evaluation of the developed solution showed that it could reduce the reliance on a rehabilitation engineer and an architect and shift to reliance on a less highly trained person, at a consequent lower cost. In public spaces, the system will make it easier to perform appropriate modifications to existing facilities. For individuals, it could provide an opportunity for professionals to evaluate physical environments where that opportunity would not otherwise exist.

The results of this study provide insight into the field applications of telerehabilitation services using advanced computer and information technologies for people with disabilities. The developments of the study show the potential for applications of virtual reality technology in the area of architectural interior environment, such as in the interior design and home renovation industries. This study also provides evidence that a virtual reality telerehabilitation system can be an alternative, cost-effective solution to conventional rehabilitation services.

As this study verified the value of the Virtual Reality Telerehabilitation System for analyzing accessibility of the physical environment, the developed Virtual Reality Telerehabilitation System could improve rehabilitation outcomes by making accessibility assessments and modifications available to a larger portion of the population of wheelchair users.

CHAPTER 2: LITERATURE REVIEW

2.1 Accessibility and Home Modification

As the ICF identifies environmental factors as a key component in defining the concept of disability, the environment is considered an important factor influencing an individual's ability to function with a disability [8]. Home modifications are adaptations to the living environment intended to increase ease of use, safety, security, and independence. Modifications can include the following: 1) changes or additions to the structure (e.g., widening doorways, adding a first floor bathroom or a ramp); 2) installing special equipment (e.g., grab bars and handrails); and 3) adjusting the location of items (e.g., moving furniture) [9].

2.1.1 Significance of Home Modification

Struyk and Katsura, in their extensive study of the modifications made by older persons in order to remain in their homes, observed that dwelling modifications were frequently made when household members had activity limitations [10]. Modifying one's home through remodeling, adding adaptive hardware, and changing the arrangement of objects is an important intervention strategy used to manage chronic health care conditions, to maintain or improve functioning, to increase independence, to ensure safety, and to minimize the cost of personal care services. [11]. Therefore, the accessibility of the home environments of younger and older individuals with disabilities plays a key role in their ability to perform ordinary activities and to obtain a high quality and competitive life.

2.1.1.1 Caregiving of Elders with Dementia Related Disorders

Calkins and Namazi surveyed caregivers of elders suffering from dementia related disorders concerning modifications made to their housing units and the effectiveness of such modifications. Modifications were commonly made to manage wandering, incontinence, safety, and independence and to reduce confusion in the home setting. The article concluded that modifications to the housing unit may contribute to reductions in caregiver stress and strain [12]. Gitlin et al. stated that home environmental intervention appeared to have a modest effect on dementia patient's IADL dependence. They also reported that among certain subgroups of caregivers, the program improved self-efficacy and reduced upset in specific areas of caregiving [13]. Olson et al. outlined both beneficial and detrimental design features that facilitate or hinder caregiving [14].

2.1.1.2 For the Senior Population and Their Safety

Researchers at the Joint Center for Housing Studies of Harvard University examined the housing needs of America's senior population, and their report urged the housing industry and public policy makers to respond with home modifications, supportive services, and housing alternatives [15]. Connell et al. discussed in their article how the absence of home modification devices affected an older person's ability to perform activities and tasks. They stated that, overall, home modifications do have an impact on assisting individuals in the performance of household tasks and activities [16]. Tinetti detailed various options to counter the problem of falls in older adults and highlighted home hazard evaluations as a positive intervention [17]. Steinfeld and Shea, in their research, discovered that barriers were extremely underestimated when elders were asked to self-report on the condition of the housing unit [18]. In their presentation of "Guideline for the Prevention of Falls in Older Persons" at the Panel on Falls Prevention, the American

Geriatrics Society, the British Geriatrics Society, and the American Academy of Orthopaedic Surgeons presented stressed that when older patients at increased risk of falls are discharged from the hospital, a facilitated environmental home assessment should be considered [19].

2.1.1.3 For Youth and Children with Disabilities

Overton emphasized that home modification is important to younger as well as to older persons with disabilities by stating that home modifications can prevent accidents, facilitate caregiving, make it easier to carry out tasks such as cooking and cleaning, facilitate engagement in major life activities, and even minimize the need for costly personal care services or institutional care [20]. Likewise, Olsen et al. addressed in their book the importance of making homes accessible for children with disabilities, as many parents raising disabled children were unprepared for the impact of inaccessible homes after the children mature [21].

2.1.1.4 For Persons with Mobility Impairment

Pynoos pointed out that a large number of disabled persons live in housing that lacks supportive features and that presents barriers to mobility, These conditions impede caregiving and make it difficult for disabled persons to carry out activities safely, thereby leading residents to give up activities unnecessarily or to carry them out in a dangerous manner [22]. Connell et al. stated that home modifications made a positive impact on difficulties and dependence experienced by persons with mobility impairment in routine household task performance [16].

2.1.1.5 Cost Efficiency

Mann et al. stated in their article that institutional and certain in-home personnel costs can be reduced through a systematic approach to providing AT and Environmental Interventions [23]. Kochera showed a sensitivity analysis demonstrating that small changes to assumptions about incidence and cost of intervention can have a large impact on whether cost savings can be achieved from home modification [24].

2.1.2 Universal Design and Visitability

Universal design is a worldwide movement that approaches the design of the environment, products, and communications with the widest range of users in mind. Providing a universal environment means creating a space that neither segregates some persons nor prevents others from using it independently, but that does benefit many whose needs have not traditionally been considered [25]. Wilson reviewed the emerging trend that as medical technology advances, more people live longer with disabilities, and he stressed the need to address the importance of universal design [26]. Mace stated that Universal design in housing is both accessible and barrier-free, but that it goes far beyond the minimum specifications and limitations of legislated mandates for accessible and barrier-free facilities [27].

Visitability is an affordable, sustainable and inclusive design approach for integrating basic accessibility features into all newly built homes and housing. To be considered Visit-able, homes need the following: 1) one zero-step entrance on an accessible path of travel, 2) doorways that are 32 inches clear throughout the floor plan, 3) basic access to at least a half bath on the main floor. The Visitability movement is based on the conviction that inclusion of basic architectural access features in all new homes is a civil and human right and improves livability for all [28].

Universal design at the community level permits full access to social participation in community affairs and to interaction with neighbors. Visitability is an important step toward making universal access to community life a reality.

2.1.3 Accessibility Related Legislations

The Fair Housing Amendments Act of 1988 was drafted in response to continued discrimination on the basis of disability in the design and construction of new housing and sales as well as in rental and management practices in existing housing. It is the only such law applying to housing that is constructed and operated on a totally private basis. The Rehabilitation Act and the Americans with Disabilities Act both mandate certain levels of accessibility in housing that is constructed or managed with federal funds [29]. Results of Newman's research show the prevalence of dwelling modifications and unmet need for dwelling modifications in the 1978 American Housing Survey (AHS), and the 1995 AHS reveals a significant increase in modifications (from 26% to 49%) and a significant decrease in unmet need for modifications (from 42% to 27%). These changes are consistent with the introduction of the ADA in 1990, with the strengthening and stepped-up enforcement of the Fair Housing Act, and possibly with Section 504 of the Rehabilitation Act between the late 1970s and mid-1990s [30].

It was the Americans with Disabilities Act (ADA) in 1990 that ensured the requirements applied to nearly all existing facilities and to all new public construction projects. These new obligations required detailed guidance; The United States Access Board (USAB), created as a federal agency in 1973, developed the ADA Accessibility Guidelines (ADAAG). by bringing together the expertise of professionals and consumer groups, Over the years, it has defined the minimum requirements for accessibility and has generated research on best practice and materials as well as on expanded guidance for specific areas like public rights of way, trails, and recreation areas. [31].

2.1.4 Underutilization of Home Modifications

Unfortunately, the growing number of older adults and younger persons with disabilities who would benefit from home modifications has not yet been matched by a delivery system capable of responding to their needs. Based on the 1995 American Housing Survey, approximately 5.1 million (57.4 percent) of the households in which a member had an activity limitation had undergone no home modification [5]. More than half of those who need home modifications are still suffering difficulties from underutilization of home modifications. Duncan addressed the problem that the ability to meet this growing need for home modifications has been hampered by lack of information, limited funding, and inadequate services [32]. Unfortunately, a number of obstacles stand in the way of securing modifications for those who need them, such as 1) unclear policy responsibilities, 2) inadequate and medically based reimbursement programs, 3) lack of adequate environmental assessments, 4) reluctance by older adults themselves to change their environment, and 5) an undeveloped service delivery system [10].

2.1.4.1 Financial Issues

One of the critical reasons those who need home modifications are not getting their needs met is the reimbursement problem. As with almost all affordable housing initiatives, most home modification programs directed at helping people with low incomes are plagued with insufficient funds. But, as recognition of the importance of home modifications spreads within society, funding sources are becoming more diverse and the amount of reimbursement is increasing . Many states and communities offer home modification programs to help some homeowners pay for necessary changes. Local community development or social service agencies usually administer these programs using combinations of state and federal funds. Different types of funding programs may be available depending on the type of home modification one needs, as follow [33]:

- Medical deduction on the individual's Form 1040 income tax return,

- Impairment Related Work Expense on Form 1040 income tax return,
- Workman's Compensation,
- Private health insurance,
- Vocational rehabilitation programs,
- Center for Independent Living,
- Medicaid Home and Community-Based Services Waiver,
- Medicare program,
- VA,
- Public housing authority (Office of Community Services, Supportive Services, Section 8),
- Private foundations or community service groups (Kiwanis Club, Rotary Club, other, churches, sorority/fraternity service organizations or craftsmen's unions),

2.1.4.2 Service Delivery Issues

The service delivery problem is another critical reason that home modifications remain unavailable to those who need them The delivery system of home modification assessment is a patchwork of fragmented and uncoordinated services with significant gaps in geographic coverage and types of services available [34]. An important element in creating a home environment that is safe and supportive is an assessment of its condition and suitability, but very few dwelling units are systematically assessed. Professionals who assess the environment include architects, occupational therapists, case managers, inspectors associated with neighborhood rehabilitation programs, and energy specialists from weatherization programs [35]. Home modifications are typically delivered by a diverse set of providers, many of whom are inexperienced either with the types of problems people with disabilities encounter in their homes or with the types of modifications available to solve a particular problem [36]. Because these services, including assessment of environmental barriers and prescription of appropriate modifications, are specialized, there are relatively few professionals with the expertise to effectively provide them. As a result, individuals who need these services have had to do one of the following; find a specialist willing to travel to their home at a reasonable cost; use an inexperienced provider at the risk of creating more problems than are solved; or simply do without, which can increase dependency or result in institutionalization [11, 16].

2.2 Virtual Reality

The term "virtualized reality" (VR) was coined and introduced in a paper by Kanade. The traditional virtual reality world is typically constructed using simplistic, artificially created computer-aided design (CAD) models. VR starts with the real-world scene and virtualizes it [37].

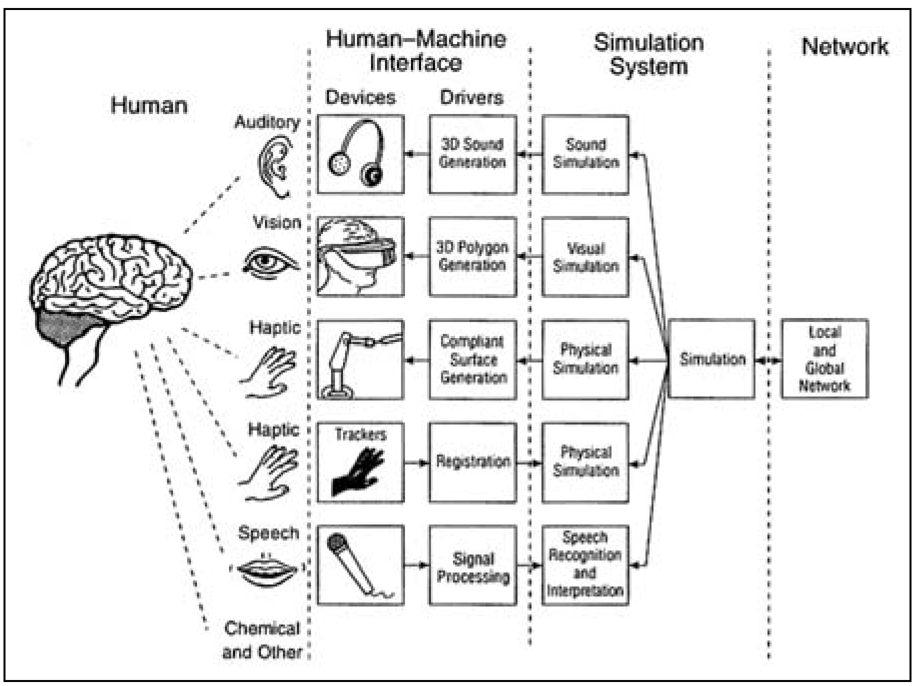


Figure 1 Organization of the computer technology for virtual reality.

The computer technology that allows us to develop three-dimensional virtual environments consists of both hardware and software. The current popular, technical, and scientific interest in Virtual Environments is inspired, in large part, by the advent and availability of increasingly powerful and affordable visually oriented, interactive, graphical display systems and techniques. As we can see, Figure 1 shows—beginning from left to right—human sensorimotor systems such as sight, hearing, touch, and speech are connected to the computer through human-machine interface devices [38].

2.2.1 VR applications in medicine

Virtual reality is becoming a practical, affordable technology for the practice of clinical medicine, and modern, high-fidelity virtual reality systems have practical applications in areas ranging from psychiatry to surgical planning and telemedicine [39]. Researchers of NASA and the University of New Mexico are developing Virtual Collaborative Clinics using telecommunication and virtual technologies to produce Earth-based models for providing expert medical advice when medical emergencies occur on spacecraft [40]. Although it may be premature to state that VR has already entered the mainstream of modern surgery, there are many signs that this technology will be used not only in the operation room, but also in preoperative planning, surgical education, and surgical research [41]. Surgical residents are using virtual reality technology to study the three-dimensional anatomy of the temporal bone, which is often difficult for students to conceptualize even after reviewing textbooks, illustrations, photographs, and cadaveric sections [42]. Already VR surgical simulators have been developed for learning laparoscopic cholecystectomy, angioplasty, nasalendoscopy, sinus surgery, arthroscopy, and gynecologic laparoscopy. Within a few years, the care of trauma patients could be enhanced through VR surgical training operations such as complex hepatic injury repair and ruptured thoracic aorta repair [43]. Samothrakis et al. introduced VRML and discussed the developing advantages of VRML in medical application [44].

2.2.2 VR Applications in Rehabilitation

Through VR's capacity to allow the creation and control of dynamic 3-dimensional, ecologically valid stimulus environments within which behavioral response can be recorded and measured, it offers clinical assessment and rehabilitation options not available with traditional methods [45]. Trepagnier described the value of VR systems for the investigation and rehabilitation of cognitive and perceptual impairments and discussed current and potential applications of VR technology to address six neurorehabilitation issues [46]. Korean researchers developed and assessed the value of a new rehabilitation training system to improve postural balance control by combining virtual reality technology with an unfixed bicycle. The system was effective as a training device; in addition, the technology might have a wider applicability to the rehabilitation field [47]. Tracy and Nathan investigated the relationship between motor tasks and participants' spatial abilities by training participants within a VR based simulator and then observing their ability to transfer training from the simulator to the real world. The study demonstrated that subjects with lower spatial abilities achieved significant positive transfer from a simulator based training task to a similar real world robotic operation task [48]. Harrison et al. applied two virtual environments to the assessment and training of inexperienced powered wheelchair users and demonstrated that the two virtual environments represent a potentially useful means of assessing and training novice powered wheelchair users [49]. And a recently completed project at the University of Strathclyde has resulted in the development of a wheelchair motion platform which, in conjunction with a virtual reality facility, can be used to address issues of accessibility in the built environment [50].

2.3 Three-dimensional Reconstruction

We have entered an era in which the acquisition of 3D data is ubiquitous, continuous, and massive. These data come from multiple sources, including high-resolution, geo-corrected imagery from aerial photography and satellites; ground-based, close-up images of buildings and urban features; 3D point clouds from airborne laser range-finding systems such as Lidar; imagery from synthetic aperture radar; and other sources. For these data to be useful, they should be employed to model the real world [51]. Mendonca and Campos investigated computer vision techniques for three-dimensional reconstruction, having as source of information non-professional images captured from cameras of arbitrary position and orientation [52]. Diener et al. tried to combine the knowledge of diverse research areas such as photogrammetric, computer graphics, and computer vision to develop new techniques for generating three-dimensional models from images [53]. An image-based acquisition and rendering system lets users interactively explore remote, real-world locations. A multisensor omnidirectional camera helps provide a compelling sense of presence [54].

2.3.1 3D Reconstruction in Medical Applications

As we have seen in the previous section, the VR environment promises lots of potential benefits in the area of medicine. In order to build the VR medical environment, 3D reconstruction from real word images has become an important technology. Gretzinger investigated an imaging method for 3D reconstruction of a test surface in order to get surface deformation information in the membrane wall models [55]. Walkin et al. demonstrated that appropriate resampling and enhancement of densely sampled freehand ultrasound image data provide high quality 3D ultrasound images which can be used in a medical diagnostic setting [56]. Jiangping et al. developed a user friendly visualization system which reconstructs three-dimensional objects from serial microscope images. They employed an algorithm called the marching cube modeling algorithm for the modeling and representation. They demonstrated the accuracy of the marching-cube algorithm by reconstructing the cubes and spheres and showed that this re-construction system is promising [57].

2.3.2 3D Reconstruction in Architectural Applications

One of the best areas to which three-dimensional reconstruction of real-world objects and scenes can be applied is the architectural environment. As technology advances in laser-scanning techniques, 3D modeling software, image-based modeling techniques, computer power, and virtual reality, 3D reconstruction of cultural heritage applications using digitization and modeling has become increasingly common [58]. Ponce et al. addressed the problem of constructing object models from various types of images. They discussed current approaches to this problem and detailed the construction of three-dimensional surface models from object outlines found in a small set of registered photographs [59]. Hujii and Arikawa introduced a method that utilizes airborne laser range images and aerial images for the 3D reconstruction of urban models [60]. Noronha and Nevatia described a system that detects and constructs 3D models for rectilinear buildings with either flat or symmetric gable roofs from multiple aerial images [61]. Policarpo presented a method to output the 3D structure of an urban area from only one aerial photo [62].

For 3D reconstruction of indoor environments, Sequeira et al. presented a new 3D scene analysis system that automatically reconstructs the 3D model of real-world scenes from multiple range images acquired by a laser range finder aboard a mobile robot [63].

2.4 Photogrammetry

The reconstruction of 3D shape from 2D visual images is a primary goal of computer vision. Active methods such as range finding or laser striping are accurate but require expensive equipment. This has motivated work in the area of passive techniques which seek to infer 3D depth information from one or more 2D intensity images [64].

Photogrammetry can provide a cost-effective alternative solution. Photogrammetry, which loosely translates from the Greek, 'light drawn to measure', is the technique of obtaining measurements from photographs. With improvements in the processing power of desktop computers and the ready availability of inexpensive, user-friendly packages for image processing, using engineering photogrammetry to achieve extremely accurate 3D models has become affordable and convenient. The range of potential uses is extensive, with the following applications under active consideration: 1) optimizing equipment siting, 2) production of synthetic environments, 3) refit planning and monitoring, 4) damage assessment and repair, 5) design modification planning and visualization, 6) computer-based and virtual reality training, 7) generating a visual database of an historic building, and 8) crime scene reconstruction [65]. Knyaz and Zheltov presented a photogrammetry system to provide an accurate and productive means of generating adequate 3D models of historical objects, which realized vision-based technique for photorealistic 3D reconstruction of historical items [66]. Debevec et al. introduced a photogrammetric modeling tool that allows the user to build a geometric model of an architectural scene based on a set of photographs [67].

2.5 Telerehabilitation

2.5.1 Definition and Introduction

Telerehabilitation is a subcomponent of the broader area of telemedicine. Cooper et al. defined telerehabilitation as the application of telecommunication, remote sensing and operation technologies, and computing technologies to assist with the provision of the delivery of medical rehabilitation services at a distance [68]. Ricker et al. defined it as the application of telecommunication technology to provide at a distance support, assessment, and intervention to individuals with disabilities [69]. Seelman abbreviated telerehabilitation to “TeleRehab” [70], and Lathan et al. defined it as using telecommunication technology for remote delivery of rehabilitative services such as monitoring, training, and long-term care of persons with disabilities [71].

TeleRehab can help people with temporary or permanent mobility impairments to surmount many transportation barriers and to schedule encounters with specialists within a shorter waiting period. It also enables the monitoring of wounds and pressure ulcers when the patient is at home [72]. TeleRehab has its challenges and is not designed to replace the traditional therapy environment. It does, however, provide an alternative to traditional therapy as adjunctive treatment, or, in some cases, it may be all that is available to certain individuals. In using this medium, the teletherapist will be challenged in many different ways, but the rewards are well worth the investment [73]. Telerehabilitation faces many hurdles before it can mature. There remains a pressing need for scientific evidence of telerehabilitation's efficacy. Credentialing issues must be dealt with and cost and reimbursement concerns addressed [74].

2.5.2 Technologies

Cooper et al. stated that the technology available for practicing telerehabilitation is significant and is expanding at a rapid rate. Currently, plain old telephone systems (POTS) and broad-band videoconferencing equipment, Internet and World Wide Web, and embedded processor systems are most widely available. These technologies continue to evolve as do emerging technologies, such as wearable sensors which will have telerehabilitation applications. Issues of payment, safety, liability, and licensure need to be resolved, as legislation tends to slow the development of new technologies [68]. Winters reviewed telecommunication technologies from the perspective of systems models of the telerehabilitation process, with a focus on human-technology interface design and special emphasis on home and mobile technologies [75].

2.5.2.1 WWW and Information Technologies

Lee et al. developed a real-time remote patient monitoring service through World-Wide Web (WWW) which allows physicians to monitor their patients in remote sites using popular Web browsers. This system provides information on patients currently being monitored and allows the user to observe a stream of vital sign data on a specific patient in real-time, such as ECG, respiration, temperature, SpO_2, invasive blood pressure, non-invasive blood pressure, and others [76]. Grims et al. demonstrated a World Wide Web-based telerehabilitation platform in a laboratory environment. This platform allowed rehabilitation providers to thoroughly evaluate the progress of a patient remotely with the same care and measurement precision that would be possible if the provider and the patient were in the same room [77]. Reinkensmeyer et al. designed a telerehabilitation system for arm and hand therapy following stroke. The system consisted of a Web-based library of status tests, therapy games, and progress charts, and could be used with a variety of input devices, including a low-cost force-feedback joystick capable of assisting in or resisting movement [78]. Magjarevic et al. investigated the acceptability and usability of information technology as one means of psycho-social rehabilitation of paraplegic and quadriplegic patients with spinal cord injury [79].

2.5.2.2 Artificial Intelligence

Wang and Winters implemented a mobile telehealth application system that uses either PocketPC or Laptop computers with various types of wireless communications. And they applied the embedded expert system moduls based on neurofuzzy technology [80]. O'Brien and Winter developed a fuzzy EMG-to-muscle force estimator that captures dynamic muscle properties while providing robustness to partial data [81]. Silverman tried to apply neural net assisted automation technology to rehabilitation service delivery. He showed that Artificial Intelligence (found on neural net recognition of movement disorders) has the potential to carry out many of the routine rehabilitation activities normally supervised by a therapist [82].

2.5.2.3 Haptic and Wearable Technologies

Girone et al. developed the "Rutgers Ankle," a Stewart platform-type haptic interface designed for use in rehabilitation. The system supplies six-DOF resistive forces in response to virtual reality-based exercises running on a host PC. The Stewart platform uses double-acting pneumatic cylinders, linear potentiometers as position sensors, and a six-DOF force sensor [83]. Winters and Wang addressed the potential influence of emerging wearable and wireless technologies on future telerehabilitation. Whether it be smart shirts with embedded physiologic vital sign signals or distributed sensing technologies that wirelessly communicate with a wearable personal digital assist (PDA) technology, wearable sensing and computing technologies are gradually emerging [84].

2.5.2.4 Virtual Reality in telemedicine

Many cases have applied Virtual Reality technology to telemedicine and telerehabilitation service development. Because telemedicine focuses principally on transmitting medical information, VR has potential to enhance the practice. Riva and Gamberini described the state of the art of VR-based telemedicine applications. This technology is now used in remote or augmented surgery as well as in surgical training, both of which are critically dependent on eye–hand coordination. Recently, however, different researchers have tried to use virtual environments in medical visualization and for assessment and rehabilitation in neuropsychology [85]. Rizzo et al. conducted three case studies for VR applications that are Internet deliverable and they identified technical, practical, and user challenges of remote VR treatment programs [86].

To improve our understanding of deficits in autism and in left visual-spatial neglect, Trepagnier et al. investigated face gaze behavior in autism and right hemisphere stroke, using Virtual Reality and gaze sensing technology [87]. Rydmark et al. also developed an at-home stroke telerehabilitation service using virtual reality haptics [88]. Researchers from Rutgers University and Stanford University developed a Virtual reality-based orthopedic telerehabilitation system [89, 90, 91]. Viirre discussed the use of Virtual Reality technologies in the rehabilitation of patients with vestibular disorders and in the provision of remote medical consultation for those patients. He stated that an appropriately designed VR experience could greatly increase the rate of adaptation in these patients [92].

2.5.3 Real-World Applications

Telerehabilitation services can be broken down into three categories; 1) clinic to clinic, 2) clinic to patient, and 3) personal status monitoring. But there is a spectrum of various types of telerehabilitation applications; thus, in many instances, services can overlap [93]. Telerehabilitation services can also be grouped into three types of usage; 1) training and counseling, 2) assessment and monitoring, and 3) therapy [94].

Most telerehabilitation application studies can be found in the area of stroke rehabilitation [95, 96, 97, 98, 99]. Many studies have also been conducted on caring for paralyzed people, such as individuals with SCI [100, 101, 102, 103,104], TBI [105, 106, 107], and MS [108, 109]. Hufford et al. studied telerehabilitation application to treatment of adolescents with Epilepsy, [110] and Russell et al. researched Low-bandwidth telerehabilitation for patients who have undergone total knee replacement [111].

Assessments via telerehabilitation have been conducted in the area of Gait Analysis [112, 113], Neurological Diagnosis [114], and Assistive Technology support [115, 116, 117].

Telerehabilitation interventions for various kinds of therapies have been implemented, including Occupational Therapy [118], Cardiorehabilitation [119], Pressure Ulcer treatment [120, 121], and Speech Therapy [122, 123, 124]. Vocational Rehabilitation related services have also been tried using telerehabilitation technologies [125, 126, 127].

2.6 Remote Accessibility Assessment

Some developmental work has been done using a remote accessibility assessment system in rural or under-served areas. A team of clinicians at the Shepherd Center (Atlanta, Georgia) performed a case study of remote home modification evaluation using a videoconference system with a video telephone [11, 128]. This project investigated the use of televideo technology to provide remote home assessment services to patients prior to discharge so that they could function as independently as possible in their own homes after being discharged from a specialty clinic. Specifically, an assessment protocol that could be implemented using video-conferencing technology was developed, and feasibility of the remote assessment process was determined by validating it against the standard of practice: an in-home assessment by a home modifications specialist. Results suggest that remote telerehabilitation assessments have the potential to enable specialists to diagnose potential accessibility problems in home environments and to prescribe appropriate modifications regardless of the location of the client, home, or specialist.

Another effort was undertaken by Extended Home Living Services in Wheeling, Illinois. which developed a remote assessment protocol using a survey instrument, the Comprehensive Assessment Survey Process for Aging Residents (CASPAR™). CASPAR™ combines the specific concerns of consumers, building professionals, and occupational therapists in performing home modifications assessments. The CASPAR™ instrument can be mailed to residents in remote areas to obtain information about consumer priorities, activities of daily living, ability to participate in home-specific occupations, and the space, layout, and design of the residence so that home modifications can be recommended [7, 129].

Both of these studies are limited in that the dimensions obtained are not sufficient for use in specifying modifications. Both methods depend on dimensions obtained by the client, using a tape measure. The use of virtual reality technology and telerehabilitation concepts to assess the home built environments of persons with severe mobility impairments was recently proposed by University of Pittsburgh researchers [68]. The Virtual Reality Telerehabilitation System (VRTS) described here was developed as part of the proposed project. The traditional virtual reality world is typically constructed using simplistic, artificially created computer-aided design (CAD) models. VR starts with the real-world scene and virtualizes it [37]. For rehabilitation applications, this distinction is significant. The application of virtualized environment to rehabilitation services is a subset of telerehabilitation services. We contend that rehabilitation outcomes will be significantly better if clients are evaluated and trained in a virtual world derived from their own physical environments. One could also imagine mobility simulations conducted in artificially contrived virtual environments.

Han et al. developed a hybrid approach, using encoding, prescriptive-based provisions and supplementing them with performance-based methods to support compliance and usability analysis for accessibility. They developed an on-line code checking program which automated generation of an IFC (Industry Foundation Classes) project model and automated ADAAG code compliance checking. After the prescriptive-based provisions to check for compliance, performance-based methods directly test the design intent for usability of a facility by executing simulation of a wheelchair moving through space in the 3D virtualized environment [130].

A team of Israeli researchers developed and evaluated an interactive living environment model that will facilitate the planning, design, and assessment of optimal home and work settings for people with physical disabilities. This interactive model was implemented via an immersive virtual reality system which displays three-dimensional renderings of specific environments, and which responds to user-driven manipulations such as navigation within the environment and alteration of its design [131].

The study by Han et al. provides good implications to VR accessibility assessment by adapting the automated ADAAG code checking system and simulation of wheelchair maneuvering in the built environment**.** The Israeli team's study also presented a good tool to enable an optimal fit between the individual and the environmental setting by using Virtual Reality and simulation technology. However, both studies assume that the layout of the target built environment is obtainable. One of the most difficult things in simulating the wheelchair maneuvering in the built environment in order to assess the accessibility is to acquire the accurate dimension of the target physical environment. Therefore, this study developed the Virtual Reality Telerehabilitation System to reconstruct 3D virtual environments from 2D photos of the real environment and to make assessments of the target environment [132].

CHAPTER 3: ACCURACY ANALYSIS

3.1 Introduction

The VRTS requires 3D reconstruction of the physical environment. We can turn to laser scanning technologies as a fast way to acquire accurate measurements of built environments. Although active methods such as range finding or laser scanning are accurate, they require specially trained operators [133] as well as expensive laser scanning systems like Leica Geosystems HDS ranging system. Even if the company like Quantapoint provides as-built documentation using laser scanning technologies [134], this service is too expensive for practical application to individual's homes. [135]. Therefore, this study will use photogrammetry technology that constructs 3D models from 2D images, to acquire 3 dimensional views.

Several software packages that perform this task are available: Photomodeler Pro (Eos Systems Inc) [136], Imagemodeler (RealViz) [137], and Viewpoint Services (Viewpoint Corporation) [138]. Viewpont Corporation provides professional services from online advertising creation, to web-based configurator applications, to digital master model development using their visualization technology that enables designers to create uniquely interactive and visual experiences for the Web and for the desktop. However, this service is too expensive to apply to our study. Photomodeler and Imagemodeler are similar products that enable 3D reconstruction of real scenes or objects from 2D photographs. While Imagemodeler has more applications for multimedia projects than for scientific use, Photomodeler has many scientific applications and shows evidence of high accuracy, as will be described. Therefore we chose Photomodeler Pro 4.0 for use in the VRTS for the following reasons: accuracy is the most important factor in 3D reconstruction; its 3D reconstruction features best fit the requirements of our system; it provides many easy-to-use tools; and several studies support its value.

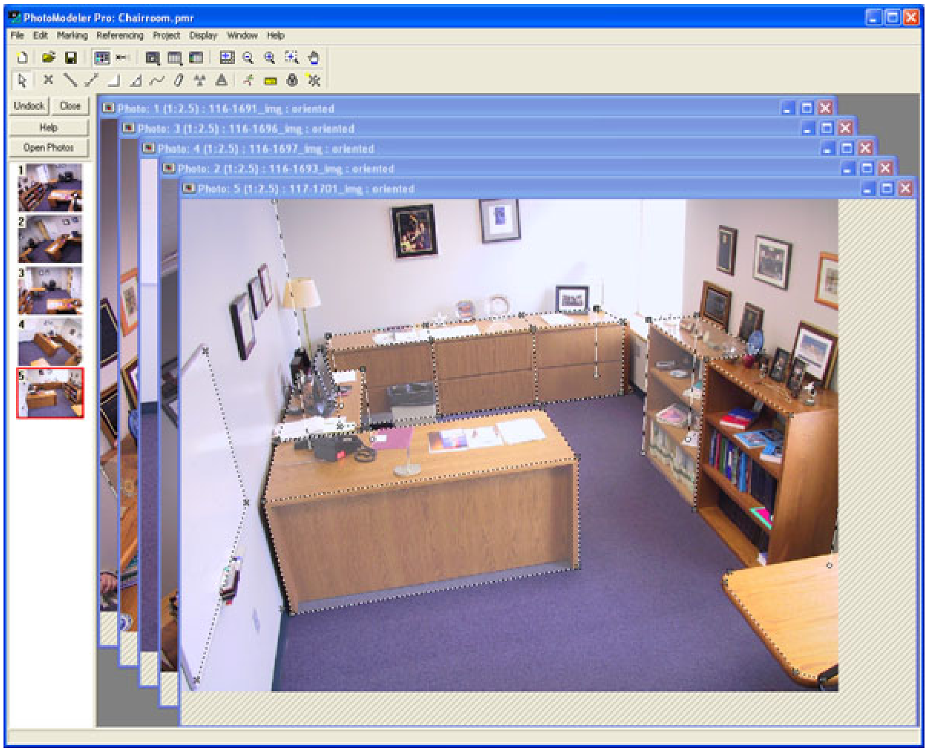


Figure 2 Marked lines and points on the photos in Photomodeler

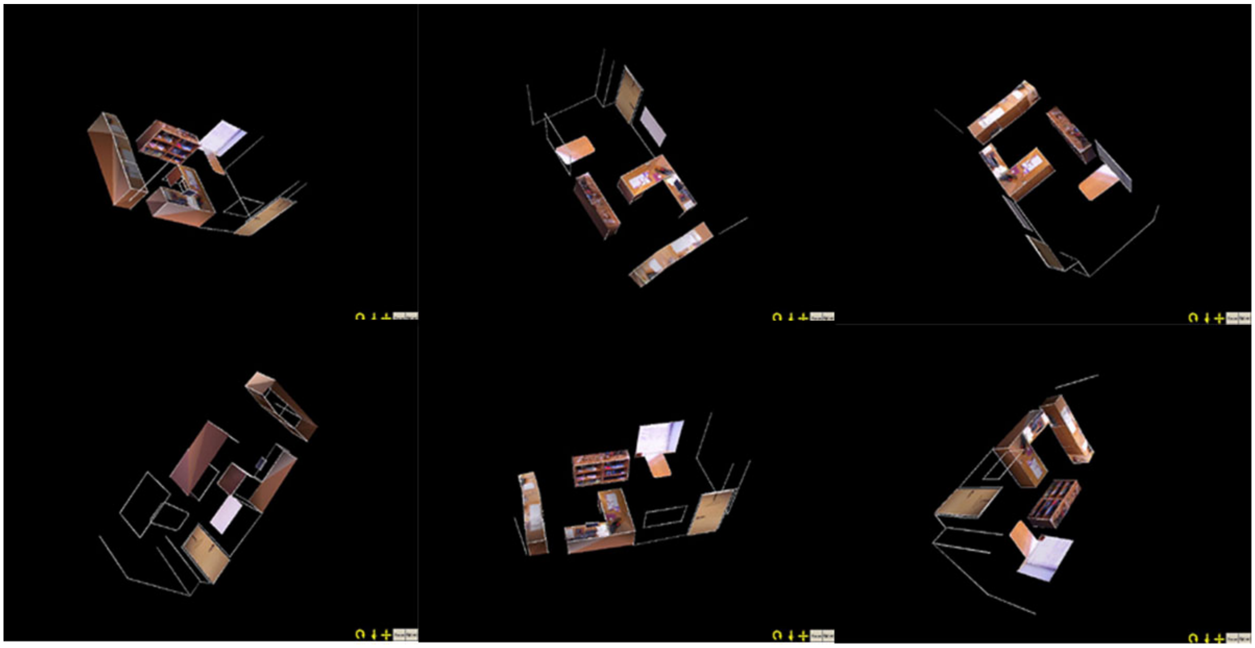


Figure 3 Rotational Views in Photomodeler

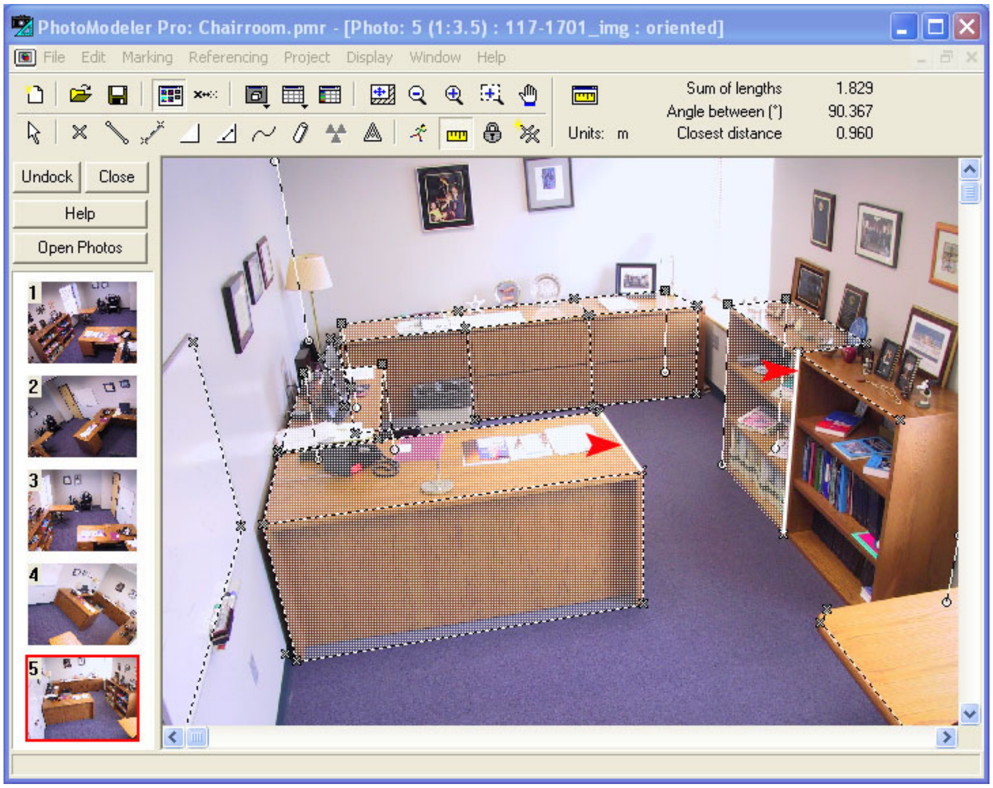


Figure 4. Measurement between two lines (desk and shelf)

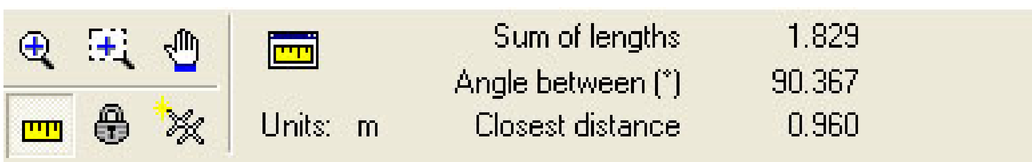


Figure 5. Display of the data at the Measurement Tool Bar

To use Photomodeler, one or more photographs of a scene or object are taken. The photographs are displayed on screen and the operator marks each photograph with the mouse, tracing and tagging features of interest (Figure2). PhotoModeler then combines the data and locates the marked features in three dimensions. The marks become accurately measured points, lines, curves, cylinders or surfaces in a single, unified 3D space. To create a 3D model from the camera and photograph marking information, PhotoModeler uses a special numerical algorithm. After attempts to build a three dimensional model are processed successfully, Photomodeler's

3D Viewer shows all objects that have valid 3D locations, and the view rotates three dimensionally around the arbitrary center of the model (Figure 3). Coordinate and distance measurements in the current project units (meters, feet, cm, etc.) are very easy to view. If we just click on the lines and/or points using the measure pointer, the measure toolbar displays information and measurements of the user-selected set of features (Figure 4, 5). Photomodeler provides extensive video tutorials as well as a comprehensive manual to help users learn to reconstruct 3D models of real scenes or objects. Based on our experience, operation of Photomodeler appears to require no special expertise beyond basic knowledge of computer graphics and design.

Lynnerup et al. applied Photomodeler to an identity verification. The software produced a 3D wire frame model based on photographs of human faces. This study showed a high degree of correct exclusion: in other words, in 14 of 15 cases, persons were correctly excluded [139]. Vedel used Photomodeler to construct a 3D model of Aarhus Cathedral, one of the oldest red buildings in Denmark,. He also employed Photomodeler successfully in his work of measuring existing buildings to create architectural documentation for renovation and expansion projects [140]. Fedak used Photomodeler to measure a set of reference points during the construction of a large ship. He worked with a relatively low-cost digital camera and retro-reflective survey targets to produce images which Photomodeler could then use to determine accurate 3D coordinates. His study showed coordinate accuracy in the order of 1:10,000, which is suitable for many applications in architecture and model building and for some industrial measurement applications [141]. A work by NASA showed that Photomodeler Pro has a high precision value of 2,800:1 [142].

However, NASA's and Fedak's applications used the software to model the exterior of objects, which differs significantly from our interior environment modeling application. We therefore needed to evaluate and verify its ability to produce a sufficiently accurate 3D model for our application.

3.2 Methods

To verify that Photomodeler Pro can produce a sufficiently accurate 3D model of the physical environment of a wheelchair user's built environment, we analyzed the accuracy of dimensional measurements in the virtualized environment of a wheelchair user's office space. The office was 6.5m by 3m. We used the Canon G1 digital camera with 3.3 mega pixel resolution [143]. We calibrated the camera with Camera Calibration 4.0 (Eos Systems Inc.) software [144].

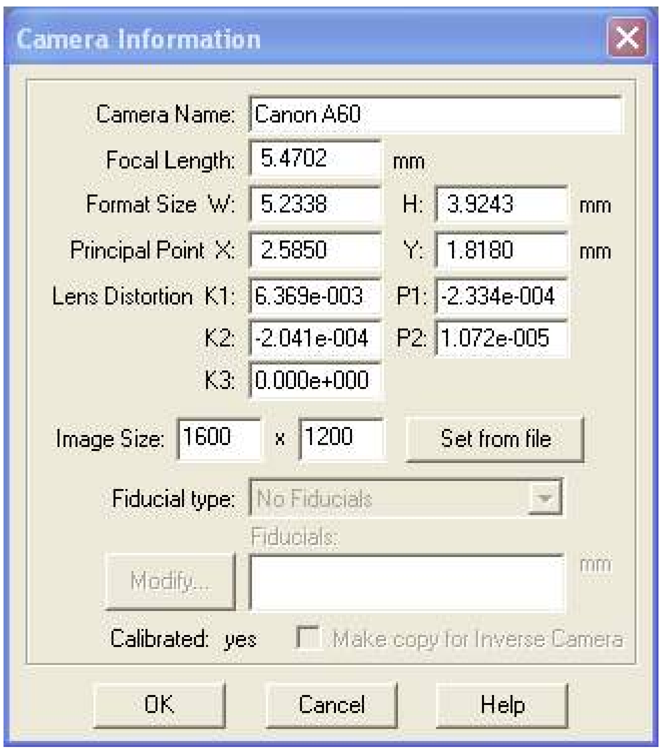


Figure 6 Calibrated Camera Information

Photomodeler uses the focal length, principal point, and digitizing scale of a camera to produce 3D models from that camera and calculates camera information such as focal length, format size width, principal point, and lens distortion parameters K1, K2, P1, P2, and sometimes K3 with its calibration process (Figure 6). Among more than 20 pictures taken, we selected five photos (Figure 7-11) to be used in Photomodeler Pro to generate a 3D model of the office space. When taking photographs, we measured the depth of the desk, the measurement of which was used to add scale to the 3D model of the office. Figure 6 shows the 3D model we then produced..

Figure 7 1st Photo of the Office

Figure 8 2nd Photo of the Office

Figure 9 3rd Photo of the Office

Figure 10 4th Photo of the Office

Figure 11 5th Photo of the Office

In order to check the accuracy of the 3D model, we identified six target objects (Figure 12): desk width, desk height, side desk width, width between desk and side bookshelf, width between desk and back drawers, and width of entrance. We measured objects with the Photomodeler Pro virtual measurement tool in the 3D model environment and with a tape measure in the physical environment.

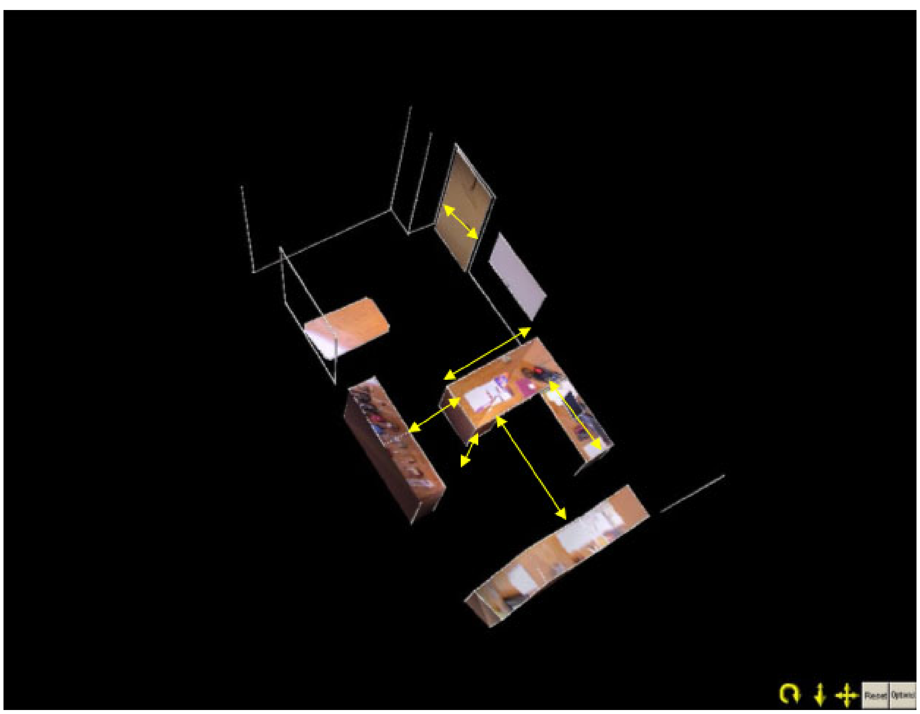


Figure 12 3D model of the Office and 6 target objects

3.3 Results

This trial showed an average precision value of 200:1 (0.51%) (Table1). This degree of precision could result in a measurement error of 4 mm (0.16″) for a typical 800 mm (32″) door opening.

(unit: cm)

	Real measurement	Calculated measurement	Deviation	Deviation ratio	Shared photos
• desk depth	76.0	76.0	Base scale		5
A) desk width	167.5	167.4	0.1	0.06%	4
B) desk height	73.5	73.2	0.3	0.41%	2
C) side desk width	122.0	121.1	0.9	0.74%	2
D) width between desk and side bookshelf	96.0	95.9	0.1	0.10%	3
E) width between desk and back drawers	180.5	180.5	0.0	0.00%	2
F) entrance width	91.1	93.6	2.5	2.74%	2
Mean	--------	--------	0.7	0.51%	2.5

Table 1 Measurement Precision in centimeter of 6 targets in a room

3.4 Discussion

We expect that objects appearing in three or more photos will be measured with higher precision than will objects appearing in only two photos. No operator can mark a point perfectly, and occasionally the targeted point registers as fuzzy or difficult to position exactly in the photograph. If Photomodeler has good Camera Station positions but imprecise point locations in the photographs, the projected 3D point will be inaccurate. To reduce this problem, we would mark the desired point in three or more photographs. That way, if the point were positioned incorrectly on one of the photographs, the other two photographs could compensate for it. If it were marked on only two photographs, errors would be undetectable, and less accuracy thus ensured in creating 3D points.

After the first trial using Photomodeler Pro, we recognized that the accuracy of the virtualized environment is affected by image quality and by the amount of time and effort the person developing the model commits. We achieved a higher accuracy level in the first trial than in later trials because we took more pictures and because our marking and referencing efforts in Photomodeler were more deliberate. But too many hours were spent on this project relative to later projects, as we can see in Table 3. Later projects required less time because the operator had gained experience using the software and because we had developed guidelines for taking photographs. An experienced architect on our research team suggested that the precision value of 30:1 is tolerable accuracy for assessing wheelchair accessibility. Sanford et al produced a similar tolerance level in their study [11]. They stated that because all measurements would be field verified by a contractor prior to construction, measurements within approximately an inch during the assessment process were generally adequate. Our analysis showed that our studies' average precision level was much more accurate than the suggested minimum acceptable level. As shown in Table 1, the error ranged from undetectable at the width between the desk and back drawers to 36:1(2.75%) at the width of the entrance.

3.5 Conclusion

Photomodeler Pro was determined capable of producing sufficiently accurate 3D models to assess of the accessibility of a wheelchair user's home. Based on the results of the accuracy analysis, we concluded that the virtual reality assessment using Photomodeler Pro would be an appropriate and useful intervention tool for accessibility assessment of the wheelchair user's home environment.

CHAPTER 4: COMPARISON OF CAMERA SYSTEMS

4.1 Introduction

Usability was a primary consideration for the VRTS design. Because the proposed technique of 3D reconstruction is based on object image acquisition, techniques and logistics involved in acquiring images are critically important [145]. The process of generating the 3D model from images is somewhat labor intensive in that it takes a trained individual about 2 hours to generate a model of a typical interior room with 4 walls. In order to limit the number of visits to the remote site, it is desirable to develop an image acquisition protocol that can be performed by an untrained individual without direct supervision. It is therefore impractical to require the use of expensive and/or sophisticated camera equipment even though high resolution is the most important factor in camera selection. Such equipment would likely be too complicated to use effectively without training and too valuable to risk being lost or damaged by an untrained and unsupervised user. To overcome this problem, we proposed that inexpensive disposable cameras or consumer grade digital cameras be used on site by untrained individuals—either consumer themselves or caregivers. To study these alternatives, we have compared the modeling accuracies of four different cameras/camera settings including a disposable camera and three digital camera variations [146].

4.2 Methods

We compared measurement accuracy for four camera types: a disposable camera (Giant Eagle, disposable film camera with 1.5 mega pixel photo CD scan [147]); an inexpensive consumer level digital camera (Canon A10, 1.2 mega pixel [148]); a high resolution digital camera (Canon G1, 3.3 mega pixel); and a high resolution digital camera with a wide angle lens (Canon G1, 3.3 mega pixel with Canon Wide Converter WC-DC58, 0.8 x wide [149]). Images from each camera were used to assess the bathroom of a wheelchair user's house. The test procedure was as follows:

1. Each camera was calibrated using Camera Calibration 4.0 (Eos Systems Inc.) software.
2. A person unfamiliar with the project was instructed how to use each of the four cameras and how to take photograph the physical environment in order to make appropriate 3D models.
3. Ten or more photos per camera type were taken of the same bathroom.
4. The dimensions of 10 objects in the bathroom were measured manually to the nearest 0.1cm using a tape measure (Figure 13).

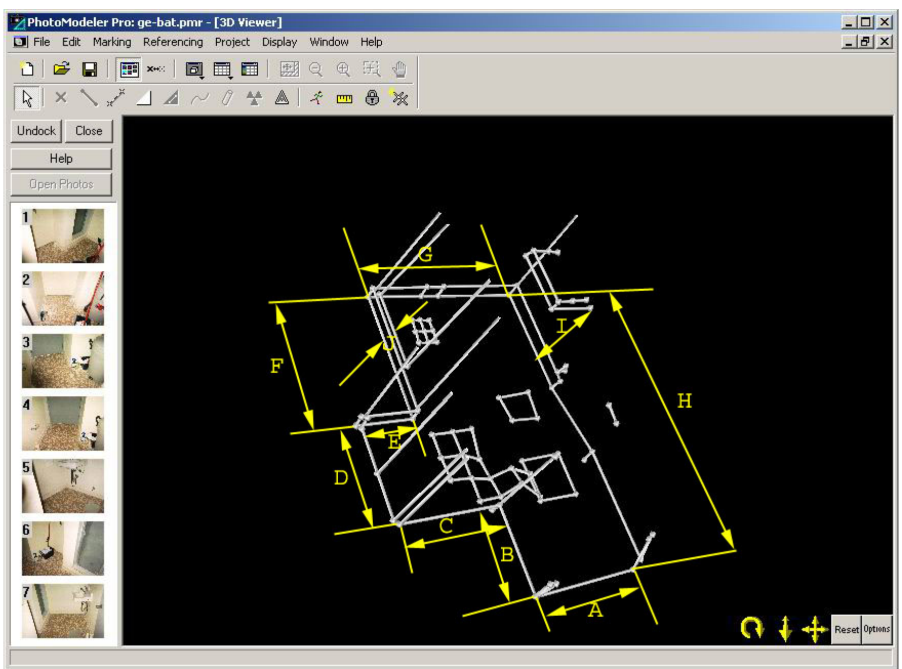


Figure 13. Taget objects to measure in a bathroom

5. One 3D model was created from images acquired from each camera setting (Figure 14 – 17).

6. The dimensions of 10 objects from the bathroom were extracted from the models and compared with the measurement by tape measure.

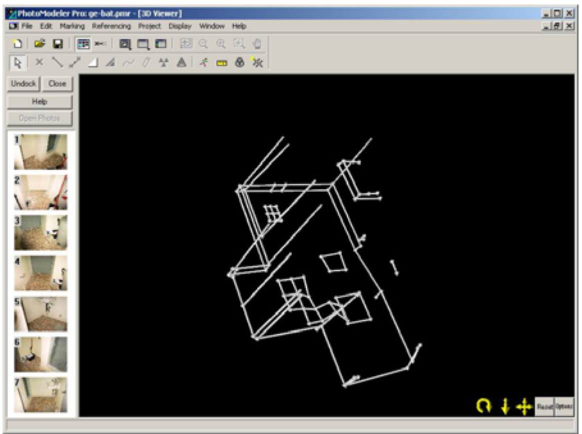


Figure 14 3D Model of a Bathroom through the Disposable Film Camera

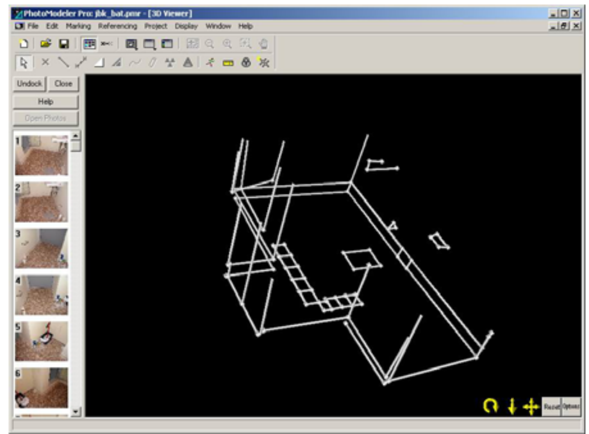


Figure 15 3D Model of a Bathroom through Canon A10 Digital Camera

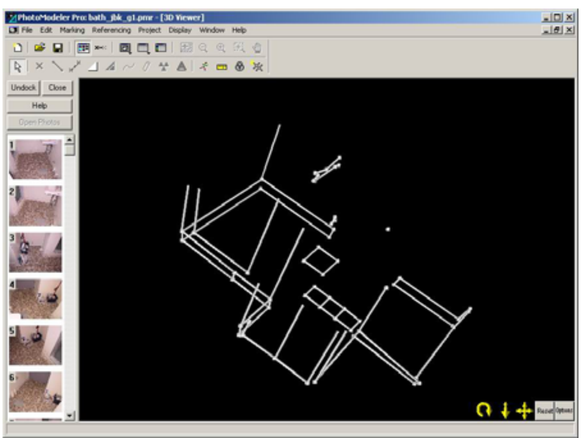


Figure 16 3D Model of a Bathroom through Canon G1 Digital Camera

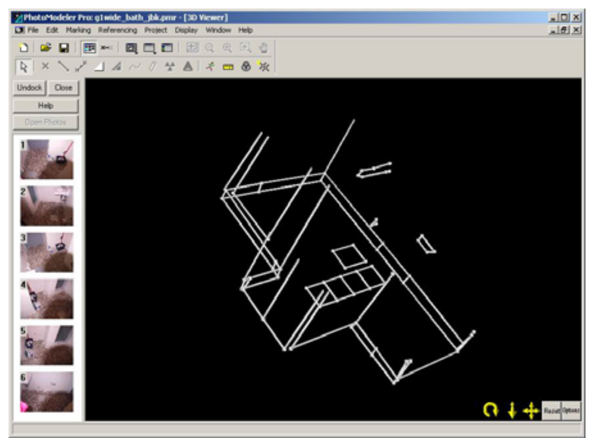


Figure 17 3D Model of a Bathroom through Canon G1 with Wide Lens

4.3 Results

Table 2 shows the comparison of measurements of 10 target objects taken from four different 3D models of the target bathroom. Deviations between each object's measurement as determined by tape measure and its measurement within each 3D model were calculated. The model generated from images created by the disposable camera showed the lowest precision, 39:1. The models generated from the A10 and G1 camera images produced precision values of 59:1 and 63:1 respectively. The model generated from images by the G1 camera with a wide-angle lens showed the most accurate measurements with highest precision, 200:1. The models generated from the disposable, G1, and A10 cameras used seven photos. The model generated from the G1 with wide-angle lens used six photos.

(unit : cm)

Object	Tape	Disposable Camera			Canon A10 Camera			Canon G1 Camera			G1 Wide Lens		
	Measure	Measure	DEV	Ratio	Measure	DEV	Ratio	Measure	DEV	Ratio	Measure	DEV	Ratio
A	91.6	92.1	0.50	0.005	92.4	0.80	0.009	93.5	1.90	0.021	91.6	0.00	0.000
B	62.4	66.7	4.30	0.069	64.5	2.10	0.034	63.0	0.60	0.010	62.3	0.10	0.002
C	77.9	79.8	1.90	0.024	76.8	1.10	0.014	77.6	0.30	0.004	77.4	0.50	0.006
D	76.8	78.3	1.50	0.020	77.8	1.00	0.013	77.2	0.40	0.005	75.7	1.10	0.014
E	42.0	44.0	2.00	0.048	43.0	1.00	0.024	43.5	1.50	0.036	41.6	0.40	0.010
F	103.2	103.4	0.20	0.002	105.4	2.20	0.021	103.0	0.20	0.002	102.9	0.30	0.003
G	135.0	135.1	0.10	0.001	136.8	1.80	0.013	134.5	0.50	0.004	134.3	0.70	0.005
H	242.5	244.3	1.80	0.007	244.3	1.80	0.007	247.0	4.50	0.019	242.2	0.30	0.001
I	78.0	77.1	0.90	0.012	77.8	0.20	0.003	77.0	1.00	0.013	77.0	1.00	0.013
J	20.0	18.5	1.50	0.075	19.4	0.60	0.030	19.0	1.00	0.050	20.0	0.00	0.000
Ave.			1.47	0.026		1.26	0.017		1.19	0.016		0.44	0.005
Precision				39:1			59:1			63:1			200:1

Table 2 Measurements from 5 different environments of the target bathroom

4.4 Discussion

Table 2 shows that one camera is not always consistently better than another across objects. For example, for Object A, deviation of the Canon G1 is almost four times that of the Disposable Camera, whereas for Object B, it is only 1/7th as much. This variation in relative deviation by object exists because 3D reconstruction from 2D photos depends mainly on manual marking and referencing tasks in the software. Therefore inconsistent deviations can occur within a tolerable range, just as random deviations occur even in the tape measurement of real space.

Although the model generated using the disposable camera was less accurate than models generated with the digital camera, its accuracy was within the tolerable range. The accuracy of the model generated with the low-resolution digital camera also compared well with the high-resolution camera model. The best accuracy was obtained with the high-resolution digital camera with the wide-angle lens; perhaps the larger field of view enabled better images from which to generate the model. The person performing the modeling noted that images from the high resolution G1 camera were easier to use in the modeling procedure and therefore required less time to process than did images from the disposable or low-resolution cameras. Although the disposable camera produced less accurate models than did the other camera configurations, its models are likely sufficiently accurate for assessing wheelchair accessibility. That is, its average deviation level was within the suggested tolerable accuracy level, 30:1. Moreover, the disposable camera has the advantages of affordability and ease of use.

We can see that the higher the resolution and function of the camera, the higher the accuracy of the 3D models (Table 2). We can see, too, the decrease in labor hours to construct 3D models for the second project (Table 3). On the other hand, the high-end camera is less affordable and more difficult to use for its complicated functions. However, as the technology progresses rapidly, the current consumer level digital camera achieves higher resolution than does a high-end digital camera of three years ago. For example, while a high-performance G-series digital camera by Canon has advanced from G1 of 3.3 mega pixel to G6 of 8 mega pixel, a consumer level A-series camera by Canon evolved up from A1 of 1.3 mega pixel to A95 of 4 mega pixel. As the built environment where pictures are taken might be difficult to reach, to return in order to redo the photography would be expensive. Thus it is a good idea to take many photographs of the object being measured. The larger memory capacity allows the photographer to shoot a vast number of photos from slightly different angles in a short time, thus increasing the chance of providing good photos for constructing 3D models. Now, the consumer level camera has become more advantageous in terms of both usability and accuracy as compared with other camera settings. We then decided to use the consumer level digital camera for our further studies.

4.5 Conclusion

Through the comparison of camera systems, we concluded that a disposable film camera or a consumer grade digital camera can be used in the VRTS. Based on the results of this analysis, we concluded that the virtual reality assessment using the A10 digital camera and photomodeler Pro would be an appropriate and useful intervention tool for accessibility assessment of the wheelchair user's home environment.

CHAPTER 5: FEASIBILITY TEST

5.1 Introduction

After performing two reliability analyses on the hardware and software components, we applied these instruments to an actual built environment of a wheelchair user to demonstrate their ability to assess the accessibility of a wheelchair user's typical built environment.

Because the client and/or his/her helpers will not be familiar with the kinds of pictures needed for the 3D modeling process, we have developed a comprehensive manual providing instructions on how to take good pictures easily. After several trials of making 3D models of architectural interior environments, we established 10 fundamental rules for taking photographs.

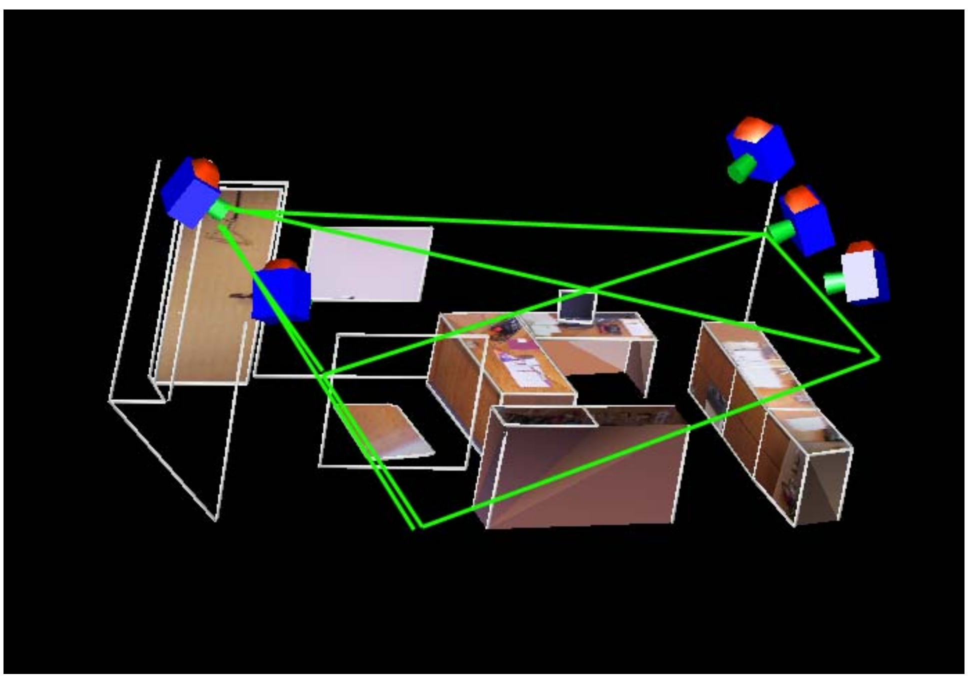


Figure 18. Image to demonstrate a good camera angle

On the basis of these rules, we developed a manual of “Guidelines for takeinggood pictures” [Apendix A], which describes each rule in detail. In this feasibility study, a photographer who is a friend of the client using wheelchair was instructed with this manual before the target home was photographed. Figure 18 shows an image in the guidelines manual that illustrates appropriate camera angles.

5.2 Methods

A feasibility test was conducted using the Canon Powershot A10 digital camera with 1.2 mega pixel resolution. The target environment was a client’s apartment unit where one of the occupants uses a standard powered wheelchair. One wheelchair user’s friend was instructed how to take the photographs using the guideline book. He took about 60 pictures, 15 pictures each per four areas of the apartment: entrance hall way, bedroom, living room, and bathroom.

After the camera was calibrated, a 3D model for each of four problem areas was generated, using Photomodeler Pro 4.0, so that dimensions of the physical environment could be easily measured in the virtualized environment. Figures below show these four 3D models (Figure 19 – 22) which were generated from the 3D modeling software, Photomodeler, based on 2D photos from listed camera settings. We used the models to identify problematic points for wheelchair accessibility by checking whether specific tasks could be performed by the client using the wheelchair.

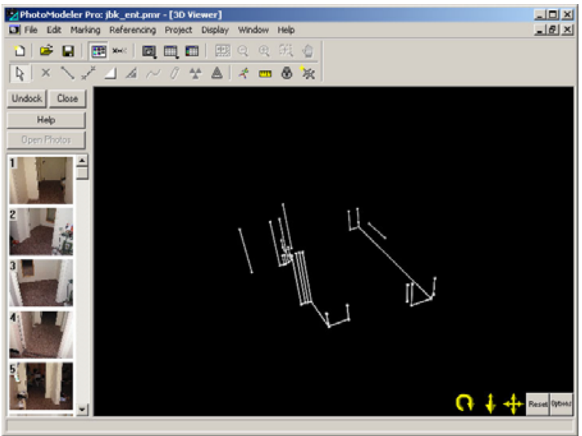


Figure 19 3D Model of Entrance

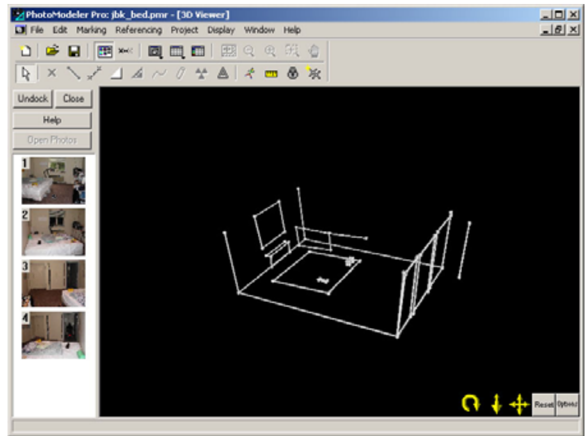


Figure 20 3D Model of Bedroom

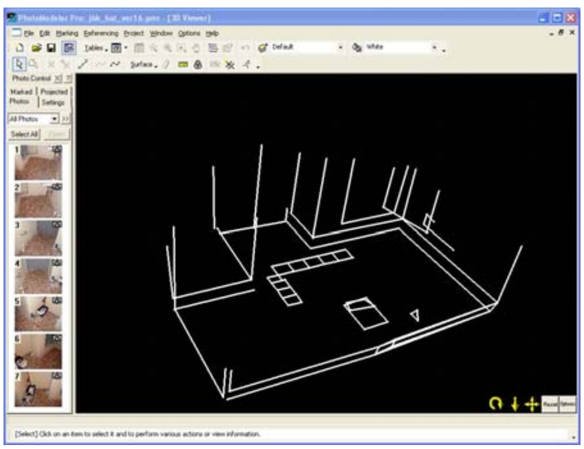


Figure 21 3D Model of Bathroom

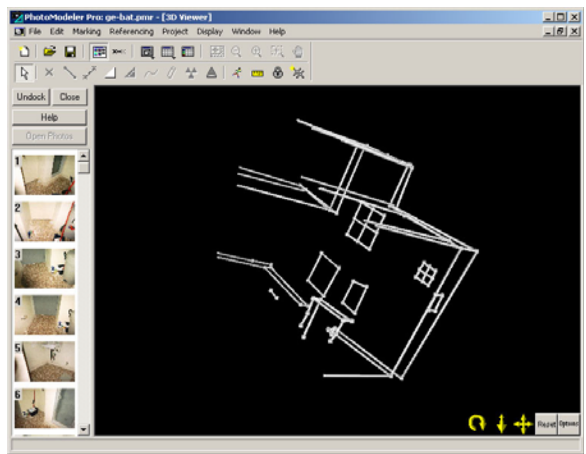


Figure 22 3D Model of Living Room

5.3 Results

Using the 3D models constructed with the Photomodeler Pro from 2D photos obtained by the Canon A10 digital camera, the investigator discovered that the kitchen doorway and bedroom doorway should be widened and the curb of the shower booth removed, but that the bathroom door, entrance door, dining table, and lavatory could accommodate the user's wheelchair. T-shape turning space of the entry also was accessible according to the ADA Accessibility Guideline (ADAAG) (Figure 23, 24) and the client's wheelchair dimension (Width: 27 inches, Length: 44 inches, Height to knee: 27.5 inches).

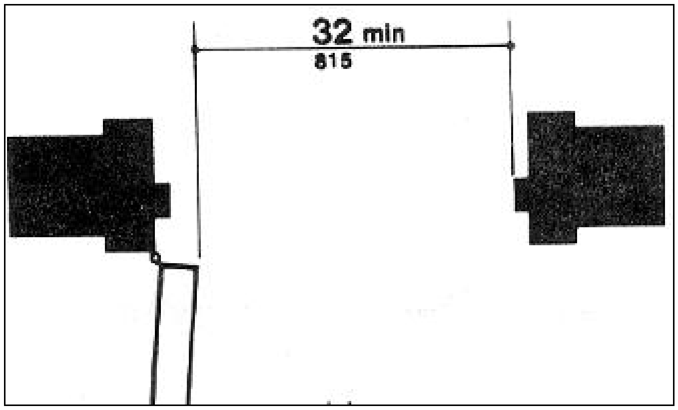


Figure 23 Clear Doorway Width and Depth Detail (ADAAG)

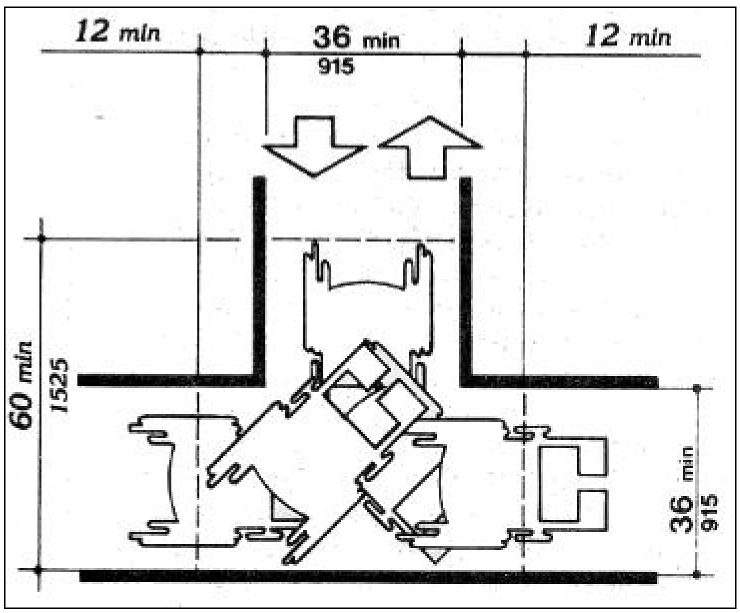


Figure 24 Wheelchair Turning Space T-Shaped Space for 180 Degree Turns (ADAAG)

We recorded time used to construct 3D models as shown in Table 3. The time decreased from the first project to the second and third projects. It took too many hours to create the first model the investigator was not accustomed to how to use the software. This includes learning time through trials and errors because the manual for Photomodeler lacks sufficient information on reconstructing interiors of the built environment and focuses rather on exterior physical environments and objects. He struggled to take appropriate pictures and to figure out how to construct a 3D model with Photomodeler. Models in this third project routinely required two to four hours to complete. Currently, we can construct a model of a area of home in 1 to 2 hours.

Project Number	Target environment	Photographer	Number of taken photos	Number of used photos	Labors for constructing 3D model
1	An office room	Investigator	91	5	7.5
2	A bath room with disposable camera	Investigator	14	7	4.5
	A bath room with Canon A10 camera		18	7	3.5
	A bath room with Canon G1 camera		17	7	3.0
	A bath room with G1 and wide angle lens		12	6	2.5
3	A living room of a client's home	A client's friend	15	9	4.0
	A bed room of a client's home		7	4	1.5
	A entrance of a client's home		11	6	2.0
	A bath room of a client's home		13	7	2.5

Table 3 Number of photos and labor hours exerted to construct 3D models

5.4 Discussion

Accessibility assessment via the virtualized environment was similar to the on-site assessment by an experienced rehabilitation engineer. That is, a rehabilitation engineer obtained similar measurements and could confirm that findings by 3D models were correct. We can see the measurements and findings from two methods in reference to wheelchair dimension and ADAAG standards in Table 4. The dimension of the client's wheelchair was 27 inches (width) by 44 inches (length) by 27.5 inches (height to knee).

	Description of measurement and findings	3D model	On-Site	Wheechair Dimension	ADAAG
Bed room	Measurement				
	clearance of doorway	27.8 in	27.8 in	W:27 in	32 in
	space around bed	36.7 in	37.5 in	W:27 in	36 in
	Finding				
	width of doorway is not wide enough	Found	Agreed		
	maneuvering around bed is accessible	Found	Agreed		
Bath room	Measurement				
	height of threshold of the shower	4.4 in	5.5 in		0 in
	clearance of lavatory	30.7 in	30.5 in	H:27.5 in	29 in
	clearance of doorway	34.4 in	33.5 in	W:27 in	32 in
	Finding				
	threshold of the shower should be rem oved	Found	Agreed		
	lavatory is accessible	Found	Agreed		
	doorway is accessible	Found	Agreed		
Entry	Measurement				
	T-shaped wheelchair turning space	46.6 in	47.5 in	L:44 in	36 in
	clearance of entrance doorway	34.6 in	33.7 in	W:27 in	32 in
	Finding				
	wheelchair turning space is enough	Found	Agreed		
	Entrance is accessible	Found	Agreed		
Living room	Measurement				
	clearance of opening from entry	34.4 in	35.0 in	W:27in	32 in
	clearance of kitchen doorway	27.0 in	27.5 in	W:27in	32 in
	clearance of dining table	28.4 in	29.0 in	H:27.5 in	27 in
	Finding				
	Entry opening is accessible	Found	Agreed		
	Kitchen doorway is narrow	Found	Agreed		
	Dining table is accessible	Found	Agreed		

Table 4 Assessment results of the feasibility test

Because this is a pilot study for further comprehensive field trials, the assessment was performed only to test the applicability of the software and hardware with a simple procedure**.** But we are developing a comprehensive and systemic evaluation form so that the architect or rehabilitation engineer can assess the accessibility objectively. As shown in the example checklist of tasks for the evaluation of accessibility in Table 5, we broke down activities into task components which can be more readily understood in terms of functional capabilities. We referred to the CASPAR™ in order to develop checklist items. In addition to the tasks of the CASPAR™, we added some features necessary to wheelchair users, such as whether there is enough space to build a ramp or to install a stair glide or lift. Besides measurement of dimensions, the physical environment could be assessed more comprehensively and objectively by checking what tasks are problematic in a given space.

A. Entrances to the home		# : A- ( )	
check		Location	Type
A01	check	Having enough space to build a ramp.	
			Specify the modification
A02	check	Having enough space to install a stair glide.	
			Specify the modification
A03	check	Having enough space to install a lift or elevator.	
			Specify the modification
A04	check	Reaching the entrance from the street, driveway or sidewalk.	
			Specify the modification
A05	Check	Maneuvering at the entry door.	
			Specify the modification
A06	Check	Going through the entry door.	
			Specify the modification
A07	Check	Going up and down stairs.	
			Specify the modification
A08	Check	Locking or unlocking the entry door.	
			Specify the modification
A09	Check	Opening or closing the entry door.	
			Specify the modification
A10	Check	Going over the threshold at the entry door.	
			Specify the modification
A11	check	Other (specify) :	
			Specify the modification

Table 5. Check-list for the entrance assessment

In order to assess the accessibility of the wheelchair user's built environment, we need preliminary information about medical diagnosis, mobility aids, and home environment of the client, especially what the customer wants and needs for home modifications beyond the measurement of dimensions.

We are also developing a survey form with the referral to CASPAR^{TM} in order to gather information about them. As shown in the sample survey form in Figure 25, the house structure will be broken into several areas and each area will be detailed by occupational tasks that the customer might have difficulties performing. We can get consumers' opinions sufficiently from this survey before measuring and evaluating the target environment.

b) Problems

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting to any entrance from the street, driveway or sidewalk.
- ❑ Maneuvering any entry door.
- ❑ Going through any entry door.
- ❑ Going up and down stairs to any entry door.
- ❑ Locking or unlocking any entry door.
- ❑ Opening or closing any entry door.
- ❑ Going over the threshold at any entry door.
- ❑ Other (specify) : ______________________________.

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task

Device : ______________________________.

Figure 25 Survey form for preliminary information

As we can see in Table 3, the third project shows remarkable improvement over the first project in constructing 3D models. The client's friend had no previously familiarity with this 3D modeling concept and was educated through our developed guidelines. The investigator now could construct 3D models within acceptable labor hours with the photos taken by the client's friend. This improvement can be attributed to two factors: One is the learned skill of the investigator; he got used to handling the program. Another is that the guidelines for taking efficient photos have been set.. Although there could be a learning effect of the investigator for handling the software program, we can conclude that the guidelines also are effective for educating a naïve photographer on how to take efficient pictures for constructing 3D models of an interior physical environment. However, we need to conduct a randomized controlled trial to validate the reliability of our developed guidelines as another further study.

5.5 Conclusion

This field feasibility test of the hardware and software instruments, adapted through a first and second analysis, showed these instruments to be appropriate. Based on results of the above reliability analyses, we concluded that the virtual reality assessment using the A10 digital camera and Photomodeler Pro would be an appropriate and useful intervention tool for accessibility assessment of a wheelchair user's home environment [150].

CHAPTER 6: FIELD TRIALS

6.1 Introduction

Through the previous pilot studies, we were able to confirm that the VRTS could be an alternative and efficient method to provide accessibility assessment service to underserved areas. And we then performed the field evaluation of the developed system in order to evaluate the VRTS as compared to the conventional method.

Three home environments were recruited in this study. Participants in this study were the owners or occupants of a home who were also clients of an architecture firm specializing in universal design. For each home environment, three cases from three imaginary subjects were evaluated. In each evaluation case of an imaginary subject and a home environment, approximately 70 tasks were assessed.

For each home environment, the architecture firm investigated the physical environment by visiting their client's house, and for each situation of the three imaginary subjects, the architect from the firm evaluated accessibility of the target home via his own conventional method.

For the VRTS method, the owner/occupant's home was photographed by a student assistant, and 3D models of the home environment were constructed from the 2D photos by a technician. Another architect then evaluated accessibility via the VRTS in the virtualized environment of the target home for each case of the three imaginary subjects.

Figure 26 Evaluation cases from three chosen homes and three imaginary subjects

The essential difference between the two methods was that the VRTS relies on dimensional data and visual information from pictures and 3D models while the CIP method relies on measurements acquired during an on-site evaluation. Both evaluators assessed a number of tasks (usually about 70) in a home evaluation by using the same evaluation form [Appendix D]. Evaluators were blinded to each other's assessment. The assessment addressseseveral problem areas of the home, and each area has a number of associated tasks. Each task was designated as problematic or not, hence, in need of modification or not, by each architect evaluator. The evaluation results of all tasks were dichotomous data that indicated whether or not specific tasks were problematic. Data were analyzed to investigate the agreement level between the results from the two methods. We calculated raw agreement indices and Kappa coefficients. Supplementary to these statistics, we also tested association between methods with the Odds Ratio and used McNemar's test to evaluate marginal homogeneity.

The goal of the current study is to determine the value of the VRTS in assessing a built environment's accessibility. Our study will test the following hypothesis:

Ho : Results from accessibility assessments of the built environment using VRTS and CIP methods are congruent.

6.2 Methods

6.2.1 Research Methodology

This study used a repeated measures research design. A home physical environment was divided into several problem areas such as entrance, hallway, bathroom, living room. Each problem area was identified by several tasks that can be performed in it. These areas and tasks were listed in the Evaluation Form [Appendix D] and were extracted from the CASPAR, introduced in Chapter 2. All possible tasks in each area within each home were evaluated using two methods: VRTS and CIP. In this within-subject design, tasks evaluated by the VRTS method would be the experimental group and the same tasks evaluated by the CIP method would be the control group.

6.2.2 Subjects

6.2.2.1 Home Owners/Occupants

The field evaluation was performed for three home environments and three imaginary subjects. A case of evaluation was matched to each imaginary subject for each home environment and each case had a sample set of about 70 matched data. The target home environments were chosen among homes of clients who had requested the home evaluation for accessibility from the architecture firmLynch & Associates. When a client participated in this research, he/she did not incur any costs resulting directly from his/her involvement. However, he/she was still responsible for any fees associated with services he/she received from Lynch & Associates through the contract for architectural service with the firm, just as if he/she were not involved in this study. He/she received $50.00 upon completion of the study for his/her participation.

Participants in this study were the owners or occupants of a house who were clients associated with the architecture firm, Lynch & Associates. Participation was strictly voluntary and all individuals were free to terminate their participation. For the evaluation via the CIP method, Lynch and Associates investigated the client's house, measuring physical dimensions with a tape measure, and the Lynch and Associates architect evaluated the client's house for each of three imaginary subjects by completing the evaluation form for this study.

The formal consent form was obtained via mail. No identifiable information on the recruited home owner/occupant was collected. He/she only made available his/her home environment so that the pictures could be taken to make 3D models of the physical environment. This is standard protocol, approved by the University of Pittsburgh IRB.

6.2.2.2 Imaginary Subjects

The actual case of the recruited client was not evaluated for comparison by the two methods because while the architect from Lynch and Associates had lots of preliminary information about his clients via interviews and discussions with them, the other architect for the VRTS had no preliminary information about the clients. If we evaluate the home environment in which the actual client lives and the second architect has to get information about the home environment of the client, her evaluation may not be very objective because she cannot visit the client's house and she must depend solely on the information from the client. Her evaluation could not be free of influence by the client's pre-assessment. This fact can severely threaten the internal validity of the research protocol.

Instead of an actual client, three imaginary subjects, Sally, Bill, and Alfred were created. Sally uses a manual wheelchair and she was injured at T11 in a car accident. Bill is a power wheelchair user with a diagnosis of spastic quadriplegia cerebral palsy. And Alfred was diagnosed with MS 5 years ago. He uses a scooter as his primary means of mobility and he can walk a short distance. The information about diagnosis and mobility aids of the imaginary subjects were filled out in the survey form by the investigator and provided to both evaluators [Appendix F].

6.2.3 Personnel

6.2.3.1 Evaluators

Two architects who are very experienced in home modifications and accessibility assessments for people with disabilities participated in this study as evaluators. They are both very renowned architects in the Pittsburgh area as home modification specialists for the accessibility of people with disabilities.

An architect from the firm Lynch & Associates Architects, who has been involved in accessibility design for more than 20 years, participated in this research study by recruiting the home subjects and evaluating the homes via the Conventional In-Person method.

In order to improve comparability between the two evaluations, a second architect whose level of experience and expertise in accessibility assessment is similar to that of the architect from Lynch & Associates took part in this study as another evaluator who evaluated target home environments via the Virtual Reality Telerehabilitation System. She is the owner of Tusick & Associates Architects, which specializes in accessibility projects and "aging in place" issues.

6.2.3.2 Investigator (Technician)

For the accessibility assessment via the VRTS, three-dimensional models of the home environment should be reconstructed from 2D photographs by using photogrammetric software, Photomodeler. To create accurate 3D models efficiently requires a technician who is used to operating the software and is experienced at making 3D models of interior structures of the built environment. In this study, the investigator of the study served as the technician; though a non-expert in photogrammetry, he has become acquainted with reconstruction of 3D models of built environments as he has performed the research of this project.

An engineer who is used to using the computer can be the technician for Photomodeler. All he/she has to do is to practice on two or three projects. There are no other prerequisites to be a technician for Photomodeler.

6.2.3.3 Student Assistant

2D images for 3D reconstruction can be acquired by a family member or friend of the client. Butbecause this study created imaginary subjects to establish the internal validity of the research protocol and because the owner/occupant of the home did not participate in the study as an actual subject, we decided to employ students in the school as part-time assistants for the photographing work. Three students were employed and each of them was sent to one of each of the homes in order to avoid the learning effect. They were instructed how to take pictures of the home environment with the developed manual for one hour before being sent.

6.2.4 Instruments

6.2.4.1 Camera

Based on the results of the previous study of camera comparison (Chapter 3), a consumer level digital camera was chosen as a reasonable instrument for this study. The Canon A60 digital camera was used in this study because it was inexpensive – around $200, had a resolution of 2 mega pixel, was not complicated to manipulate, and was easier to get good pictures from than the disposable camera for construction of 3D models in Photomodeler Pro. Most importantly, the large capacity memory card allowed the photographer to shoot a vast number of photos from slightly different angles in a short time, thus increasing the chance of providing good photos for constructing 3D models.

Figure 27Cannon Photoshot A60

6.2.4.2 3D Reconstruction Software

Currently, several kinds of software are available on the market that construct 3D models from 2D photographs : the Imagemodeler (RealViz), the Viewpoint 3D, and the Photomodeler (Eos Systems Inc). We decided to use the PhotoModeler Pro as the 3D modeling software in our study, which is the leading edge software for creating 3D models and performing 3D measurements from photos.

PhotoModeler Pro enables the creation of accurate, high quality 3D models and measurements from photographs. It is widely used by professionals in the fields of accident reconstruction, architecture, archaeology, engineering, forensics, web page design, and 3D graphics.

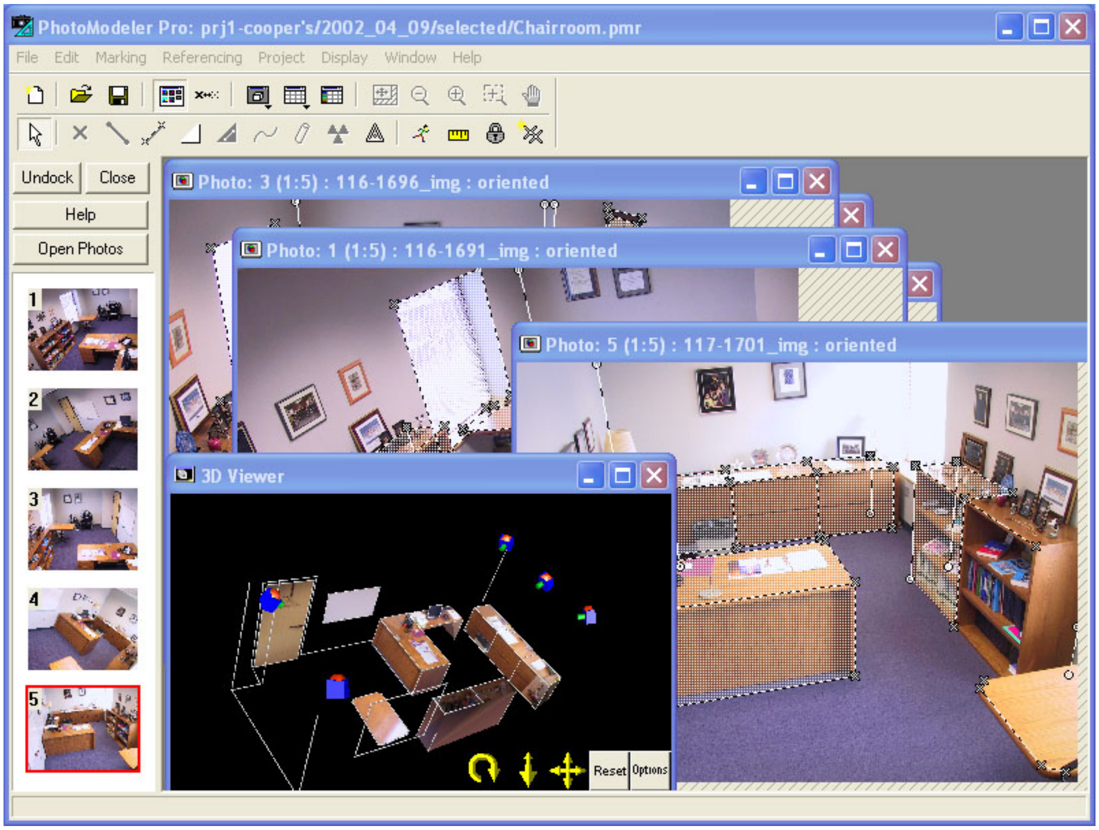


Figure 28 Photomodeler Pro

6.2.4.3 Guidelines for Taking Good Pictures

It is very important to take good quality 2D photographs in order to efficiently and accurately make 3D models of the home environment. Because the client and/or his/her helpers will likely not be familiar with the kinds of pictures needed for the 3D modeling process, we have developed a comprehensive manual that provides instructions on how to take good pictures easily.

After several trials of making 3D models of architectural interior environments, we established 10 fundamental rules, as follow, for taking photos:

1. Photos should be taken at a fixed focal length.
2. Norm objects with known dimensions (to be provided along with camera) should be placed in the middle of each target space.
3. Camera should be placed at the highest possible position with its back as close as possible to walls and ceiling.
4. The photos do not need to include the ceiling.
5. Each photo should include the floor and as many objects on the floor as possible.
6. Every point and wall intersection line of objects should be included in 2 or more photos.
7. Each photo should contain as many objects within a target space as possible.
8. Each photo should contain two or more adjacent walls and two or more vertical wall intersection lines if possible.
9. Objects that can hide the corner point and/or vertical wall intersection line must be removed.
10. The blinds or curtains must be drawn to block out extra light.

Each rule is described in detail in the guidelines manual [Appendix A]. On the basis of these fundamental rules, we wrote a manual of "Guidelines for taking good pictures." These instructions can be shipped with the camera to the customer.

6.2.4.4 Survey Form for Preliminary Information

In order to apply the VRTS to actual clients, it is very important to familiarize the home modification specialist with the target home environment in advance in order to focus on the potentially problematic areas within the home. We developed a survey form to gather information about each client's diagnosis, mobility aids, and home environment by referring to CASPAR™. We simplified the CASPAR to fit our study and developed a survey form for our study. The survey form [Appendix B] consists of three parts: mobility aids, physical environment, and client's ideas and concerns. In the mobility aids part, the owner/occupant will specify aids that he/she currently is using, such as manual wheelchair, power wheelchair, or scooter, along with their dimensions. The physical environment part is divided into seven areas as follow: Entrance to the home, Interior Stairs, Moving around the home, Using the bathroom, Using the bedroom, Using the kitchen, and Doing other activities. Each area is composed of the location of the specific architectural component and several tasks that can be performed within that area. The last section of the form allows the client to comment on the problematic areas he/she would like to change as well as areas he/she would not like to be modified. Additional recommendations can be added by the client's regional health care specialist such as a home care nurse or occupational therapist.

However, a simple survey form for the preliminary information about the imaginary subject was used in this study. Three survey forms were filled out by creating three situations with different diagnoses and mobility aids. In the mobility aids part, the investigator specified mobility aids such as manual wheelchair, power wheelchair, or scooter, along with their dimensions. The diagnosis part was detailed in terms of the medical diagnosis and functional ability of the created subject.

This survey form of the imaginary subject [Appendix C] was provided to both evaluators so that both would have the same level of preliminary information for the home evaluation.

6.2.4.5 Norm Objects

Although three pilot studies showed that Photomodeler and a consumer level digital camera are sufficiently accurate for assessing accessibility, the reliability of 3D models constructed for accessibility assessment needs to be verified because the 3D reconstruction is processed by humans and it might have errors. If the reconstructed model is not accurate, the assessment based on the model may not be reliable. In order to verify that the accuracy of the model is high enough for use in the VRTS method, we decided to use the carpenter's scale as the norm object. We adapted the 8" x 12" Empire Steel Carpenter Square and 16" x 24" Aluminum Framing Square as norm objects to validate the accuracy of the constructed 3D models. This kind of square is made to 1/32" according to the manufacturer.

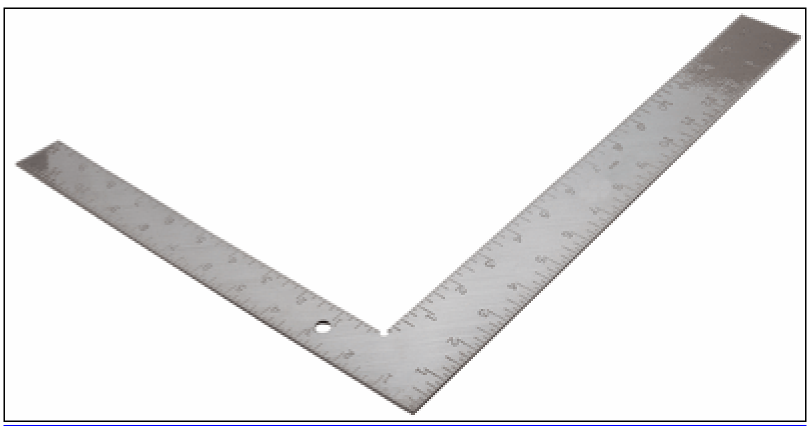


Figure 29 12" x 16" Empire Steel Carpenter's Square

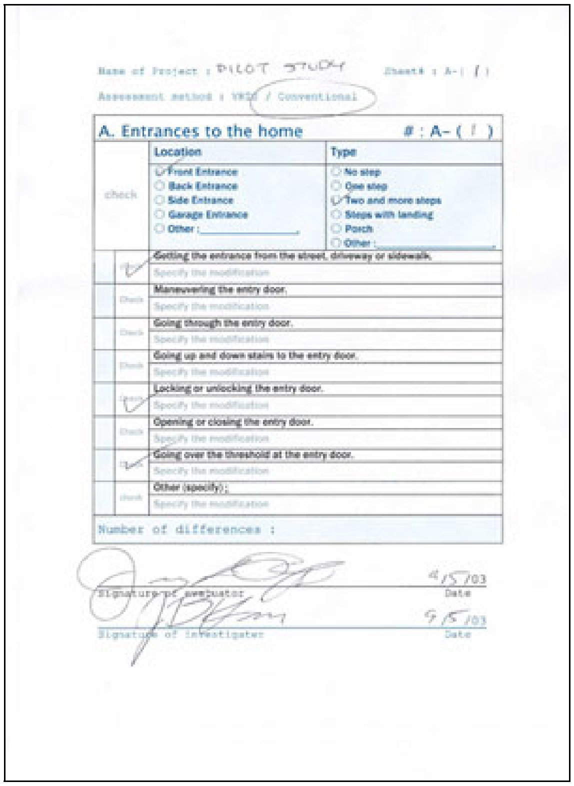
We located at least two norm objects in the middle of each problem area and took pictures of the target problem area so that the norm object could be included in as many photos as possible. Then this norm object also could be used for calibration of the space.

After the 3D model was constructed, we measured the dimensions of the squares and verified whether the accuracy of measurement was acceptable, that is, whether the deviation between the actual dimension and the dimension measured in the created 3D model was tolerable.

6.2.4.6 Evaluation Form

There are several checklists available to investigate the accessibility of the built environment for the safety of the elderly and people with disabilities. Two commercially available forms such as the Multiphasic Environmental Assessment Procedure (MEAP) and the therapeutic environmental screening scale (TESS) are instruments developed to observe nursing homes and other settings for the elderly [151]. Roberts reviewed two books that provide a comprehensive review of the current research on falls and useful guidelines for clinical application of fall risk factor assessment and intervention [152]. Several checklists and guidelines are available on the Internet, but most of them focus on safety. Therefore, we decided to refer to the CASPAR™ in order to develop the evaluation form for systemic and objective assessment of the accessibility of a wheelchair user's built environment. We adapted some of the tasks of the CASPAR™ as checklist items. In addition to the tasks of the CASPAR™, we added some features necessary to wheelchair users, such as whether enough space exists to build a ramp or to install a stair glide or a lift.

Our developed evaluation form [Appendix D] was used for each method in order to objectively compare two methods. This form allowed evaluators to easily identify potential problematic tasks and guided them through a systematic assessment. The contents of the evaluation form are consistent with the physical environment part of the survey form. That is, the contents divide into seven problem areas : A. Entrance to the home, B. Interior Stairs, C. Moving around the home, D. Using the bathroom, E. Using the bedroom, F. Using the kitchen, and G. Doing other activities. Each area contains several tasks. The areas evaluated varied from home to home, depending on each home's configuration. The set of areas to be used was decided by the investigator after the survey for the imaginary subject was filled out and the home environment was photographed.


Name of Project : PILOT STUDY Sheet# : A-(/)
Assessment method : VRTS / Conventional

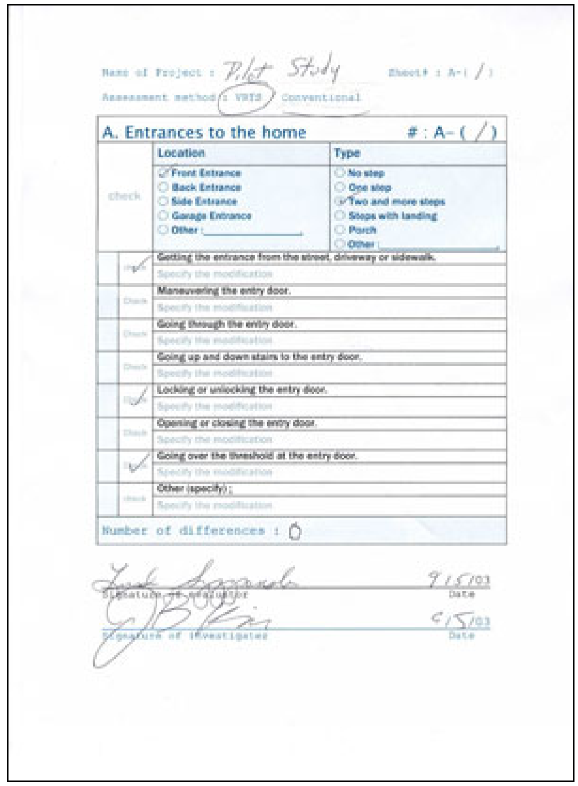
A. Entrances to the home #: A-(/)

check	Location	Type
	Front Entrance Back Entrance Side Entrance Garage Entrance Other :	No step One step Two and more steps Steps with landing Porch Other :
✓	Getting the entrance from the street, driveway or sidewalk. Specify the modification	
Check	Maneuvering the entry door. Specify the modification	
Check	Going through the entry door. Specify the modification	
Check	Going up and down stairs to the entry door. Specify the modification	
✓	Locking or unlocking the entry door. Specify the modification	
Check	Opening or closing the entry door. Specify the modification	
✓	Going over the threshold at the entry door. Specify the modification	
check	Other (specify) : Specify the modification	

Number of differences :

Signature of evaluator 4/5/03 Date
Signature of investigator 9/5/03 Date

Figure 30 An Evaluation Form of the CIP


Name of Project : Pilot Study Sheet# : A-(/)
Assessment method : VRTS / Conventional

A. Entrances to the home #: A-(/)

check	Location	Type
	Front Entrance Back Entrance Side Entrance Garage Entrance Other :	No step One step Two and more steps Steps with landing Porch Other :
✓	Getting the entrance from the street, driveway or sidewalk. Specify the modification	
Check	Maneuvering the entry door. Specify the modification	
Check	Going through the entry door. Specify the modification	
Check	Going up and down stairs to the entry door. Specify the modification	
✓	Locking or unlocking the entry door. Specify the modification	
Check	Opening or closing the entry door. Specify the modification	
✓	Going over the threshold at the entry door. Specify the modification	
check	Other (specify) : Specify the modification	

Number of differences : 0

Signature of evaluator 9/5/03 Date
Signature of investigator 9/5/03 Date

Figure 31 An Evaluation Form of the VRTS

Every task in each area was assessed for accessibility problems using both assessment methods. The CIP method was done in person and on site while the VRTS was performed in the virtualized environment. The two architects filled out this same evaluation form when they performed their evaluations. The results of the assessment for each task were recorded in the data sheet as a dichotomous value. A "0" was used to indicate that the task was not problematic, and a "1" was used to indicate that a problem was present. The task was identified as problematic in the evaluation form if the task couldn't be performed by the client**.**

Finally, the investigator compared the CIP and VRTS evaluation forms by investigating each task for each area in a client's home in order to analyze the agreement between CIP and VRTS.

6.2.5 Procedures

6.2.5.1 Recruitment

If an individual requested a home accessibility assessment through the architecture firm Lynch & Associates, a flyer (Appendix E) was distributed to him/her by the architect. The architect then instructed any interested customer to contact the investigator of this study. Customers who were interested in the study were contacted by the investigator via telephone. At this time, the investigator discussed the study and its risks and benefits in further detail. A formal consent form (Appendix F) and self-addressed stamped envelope were then mailed to potential participants, accompanied by a cover letter instructing the individual to contact the investigator by telephone prior to signing the informed consent (Appendix G) so that any questions he/she might have about the study could be addressed prior to obtaining his/her consent to participate. The investigator documented the date and time of this conversation in writing and retained this documentation with the research files. Participants returned the signed consent form to the research staff using the envelope provided, and a copy of the completed consent form was mailed to the participant.

6.2.5.2 Creating Imaginary Subjects

Instead of actual clients, three imaginary situations were created through completion of the survey form for three imaginary subjects. This survey form was filled out by the investigator in the name of each of three imaginary subjects per each house. Nine surveys were completed for each of three imaginary clients in each of three homes.

6.2.5.3 Acquisition of Images

Pictures were then taken of the client's home environment. In this study, three students of the school were recruited as part-time assistants for the image acquisition. They were instructed how to take pictures of the home environment with the developed manual for an hour before being sent. Each of them was sent to one of each of the homes with a Canon A60 digital camera and four carpenter's squares. When he/she took pictures of a problem area, at least two squares were located in the middle of the space. And he/she sketched a rough floor plan of the home environment which showed where each problem area was located.

6.2.5.4 Evaluation via the CIP

The architecture firm of Lynch and Associates conducted the Conventional In-Person assessment by visiting their client's home and investigating the physical environment. An architect and an architectural assistant measured the architectural dimensions with tape measures. The architect then examined all tasks on the evaluation form for each imaginary subject and determined what tasks presented problems and what modifications were needed. The architect completed the evaluation form with the information from the on-site investigation and measurement of his/her client's home environment. This procedure was performed before the acquisition of images.

6.2.5.5 3D Modeling

The pictures were sent back to the research center with the sketched floor plan. A technician – who is the same person as the investigator in this study - analyzed the pictures and constructed 3D models. A 3D model was made for each problem area, using the 3D modeling software, Photomodeler Pro. Once the model was constructed, the technician measured the dimensions of norm objects (carpenter's squares) in the 3D model in order to determine whether the model was accurate enough to be used for the accessibility assessment. He analyzed the accuracy of the 3D models by calculating the deviation between actual known dimensions of squares and the dimension measured in the 3D model and comparing the deviation with the tolerable level.

If the deviation of any measured dimension from the norm object was larger than the agreed accuracy level (1:30), the technician had to refine the model until it was sufficiently accurate. One way to improve the accuracy is to mark the object points more clearly in Photomodeler. If he could not obtain sufficient accuracy by re-marking, he could improve the accuracy by adding or changing the pictures used to create the model.

6.2.5.6 Evaluation via the VRTS

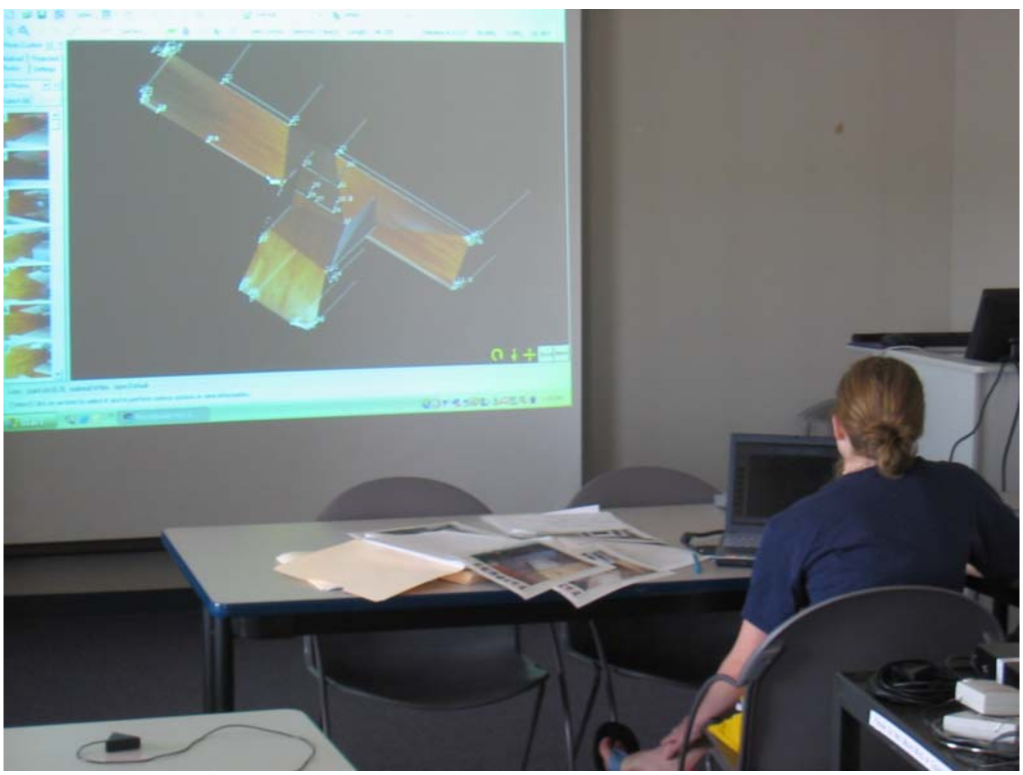


Figure 32 View of Assessment using Virtual Reality 3D Model

Once the 3D models were created with the desirable level of accuracy, they were given to another architect along with the 2D photos and a sketched floor plan. The survey form of each imaginary client was also provided with the evaluation form for each case. The architect from Tusick and Associates then evaluated the accessibility and assessed the modification requirements for each imaginary client's situation, using the virtualized model of each home environment, and referring to 2D photos and preliminary information from the survey form. She also used the evaluation form to evaluate all tasks in all problem areas in an orderly and systematic way. The evaluation form was then used to compare the two evaluations, one by the VRTS method and the other by the CIP method.

6.2.5.7 Comparing Two Methods

As described above, in order to compare two methods, each imaginary client's situation in the chosen home environment was assessed via CIP by the architect at Lynch and Associates and via VRTS by another architect from Tusick and Associates. Fist architect used the floor plan of each house that was made by on-site measurement and second architect used 3D models to evaluate the accessibility. The floor plans, sample 3D models and sample pictures are included in Appendix G. The investigator compared the data from each evaluation form, completed by the two architect evaluators, to determine the level of agreement between the evaluation results via the VRTS method and the CIP method. This field evaluation was performed for nine cases from three imaginary subjects and three home environments in order to strengthen the power of and to generalize this study for different types of home environments.

6.3 Data Collection and Analysis

6.3.1 Data Collection

In the in-person assessment, the architect himself collected architectural data about home environment by measuring the architectural dimension with tape and photographing the physical environment. And he analyzed the architectural data together with the information about the imaginary subject in the office. He recorded the assessments on the evaluation form by identifying whether each task was problematic or non-problematic for the imaginary subject to perform in the investigated home environment.

For the VR assessment, a student assistant collected image data for 3D reconstruction in the target home environment. These 2D image data were used to construct 3D architectural data in the computer. Another architect then analyzed the 2D images and 3D architectural dimension and structure along with information on the imaginary subject, and she recorded the assessments on the same evaluation form by identifying problematic tasks in the virtual reality environment.

Eventually, data for both the on-site and remote assessments were recorded on the same evaluation form. A data sheet was then constructed from the two evaluation forms; one was filled out by an architect based on the CIP evaluation and the other by another architect based on the VRTS. This created a dichotomous data set for all tasks of two evaluations.

In this study, each home had six areas and each area had around ten tasks. A total of 612 tasks were evaluated for nine cases. Table 6 shows what areas were investigated in each home environment and how many tasks were evaluated in each area.

We selected only six critical problem areas per home in order to reduce the exaggeration of results through useless evaluation of unproblematic areas. We eliminated the evaluation of simple areas with intuitive architectural structure, such as the living room, bedroom, family room, and dining room, and we evaluated the most problematic areas, such as the bathroom, kitchen, entrance, hallway or pathway, and stairs.

1st house		2nd House		3rd House	
Areas	**# of tasks**	**Areas**	**# of tasks**	**Areas**	**# of tasks**
Back entrance	10	Back Entrance	10	Back entrance	10
Stairs	6	Side Entrance	10	Stairs	6
Hallway	10	Hallway	8	Hallway	10
1st Bathroom	18	Study room	6	1st Bathroom	18
2nd Bathroom	16	Powder room	11	2nd Bathroom	16
Kitchen	13	Kitchen	13	Kitchen	13
	73		58		73

Table 6 number of tasks in each problem area

6.3.2 Analytic Strategy

To analyze the degree of CIP/VRTS agreement, CIP's assessments canbe cross-tabulated with assessments from VRTS, in which there are four possible assessment combinations as shown in Table 7. A True Positive (Checked – Checked) occurs when the VRTS method identifies the target task as problematic when it is also identified as problematic by the CIP method.

A True Negative (Not Checked – Not Checked) occurs when the VRTS method identifies the target task as non-problematic when it is also identified as non-problematic by the CIP method. A False Positive (Not Checked – Checked) occurs when the VRTS method identifies the target task as problematic when it is identified as non-problematic by the CIP method. A False Negative (Checked – Not Checked) occurs when the VRTS method identifies the target task as non-problematic when it is identified as problematic by the CIP method.

		VRTS	
		1 (Checked) Problematic	0 (Not Checked) Non-problematic
CIP	1 (Checked) Problematic	True Positive (A)	False Negative (C)
	0 (Not Checked) Non-problematic	False Positive (B)	True Negative (D)

Table 7 4 possible assessment combinations for a target task

Table 8 shows the cross tabulated data from this field evaluation. We collected nine samples of this type of dichotomous datum and analyzed them with so called “rater agreement” methods. There is little consensus about what statistical methods are best to analyze rater agreement [100]. The generic word "rater" is used here to refer to accessibility evaluation method.

		VRTS		
		Problematic	Non-Problematic	
CIP	Problematic	A=417	B=17	A+B=434
	Non-Problematic	C=19	D=159	C+D=178
		A+C=436	B+D=176	N=612

Table 8 Cross Tabulated Data of Evaluations between Two Methods

In this study, we calculated four statistical values for the 612 observed data in order to investigate the extent to which our developed VRTS agrees with the Conventional In-Person method.

6.3.2.1 Raw Agreement Indices

. As the simplest method of agreement, we reported raw agreement indices. We calculated the observed proportion of overall agreement and proportions of agreement specific to each category (home, subject, problem area, tasks) respectively [153, 154]. These proportions are interpretable as estimated conditional probabilities. In this study, the proportion estimates the conditional probability that, given that one of the methods, randomly selected, makes a positive evaluation (problematic), the other method will also do so. The overall agreement rate can be divided into sensitivity (true positive rate) and specificity (true negative rate). We also reported sensitivity and specificity. Though these statistics are very simple, they provide the opportunity to compare the results of our study with other studies' results because other studies such as the CASPAR™ and the Video Conferencing Telerehabilitation method report their results with these statistics [7, 11].

6.3.2.2 Kappa Coefficients

As a more conservative measure than simple agreement, we calculated Cohen's Kappa coefficients, which is a statistic that adjusts for agreement by chance. [155]. This is interpreted as the proportion of times raters would agree by chance alone. Kappa ranges from 0 (perfect disagreement) to 1 (perfect agreement), with kappa values of .70 and above representing good agreement, .60 – .70 representing acceptable agreement, and less than .60 representing poor agreement. However, the term is relevant only under the conditions of statistical independence of raters. Since the two methods of this study can be considered to be independent, the relevance of this term, and its appropriateness as a correction to actual agreement levels, makes sense.

6.3.2.3 Odds Ratio

Even though Kappa coefficients are used in a variety of published papers, widely growing consensus among statisticians is that kappa coefficients are vastly overused and that they should most definitely not be viewed as the default or standard way to measure agreement [152]. Thus, we also tested association between assessments by two methods with the Odds Ratio. The Odds Ratio [156] is an important option for testing and quantifying the association between two methods in creating dichotomous ratings like those in this study. In this study, the Odds Ratio means how many times higher the probability that the VRTS will identify the task correctly as being problematic than the probability that the VRTS will identify it incorrectly as problematic. With this Odds Ratio, we can determine whether the VRTS method can identify a task as problematic with significant correctness.

6.3.2.4 The McNemar test

Lastly, we used McNemar's test to evaluate marginal homogeneity. A significant result implies that marginal frequencies (or proportions) are not homogeneous. In this study, the significant result implies a tendency between two methods that one method will assess a task to be problematic which was assessed to be non problematic by the other method, or vice versa.

6.4 Results

6.4.1 Overall Agreement Rate

Category	True Response		Kappa k(p-value)	Odds Ratio [95%CI]	McNemar (p-value)
	True Positive: Sensitivity	True Negative: Specificity			
Total	94.1%(576/612)		.857(.000)	205.272 [104.062, 404.921]	(.868)
	95.6%(417/436)	90.3%(159/176)			

Table 9 Agreement Rates For Overall Observation.

We used the Conventional In-Person assessment as the baseline to compare the VRTS protocol. The proportion of overall agreement was highly observed as 94.1% and the overall sensitivity and specificity was reported as 95.6% and 90.3% respectively. As a significant Kappa coefficient of .857 and the 95% Confidence Interval of Odds rate of [104.062, 404.921] were calculated, a high level of overall agreement rate was shown. And high p-value (.868) of the McNamar test implied that there was no marginal homogeneity, that is, no tendency to identify the task incorrectly in the positive or negative direction.

6.4.2 Agreement Rates by Home, Subject, and Area.

Category	True Response		Kappa k(p-value)	Odds Ratio [95%CI]	McNemar (p-value)
	True Positive: Sensitivity	True Negative: Specificity			
1st House	93.2%(204/219)		.764(.000)	95.768 [32.392, 283.140]	(1.000)
	96.1%(173/180)	79.5%(31/39)			
2nd House	92.5%(161/174)		.851(.000)	161.950 [50.805, 516.242]	(.581)
	90.8%(79/87)	94.3%(82/87)			
3rd House	96.3%(211/219)		.896(.000)	474.375 [114.216, 1970.23]	(1.000)
	97.6%(165/169)	92.0%(46/50)			

Table 10 Agreement Rates by Home Environment.

Category	True Response		Kappa k(p-value)	Odds Ratio [95%CI]	McNemar (p-value)
	True Positive: Sensitivity	True Negative: Specificity			
Alfred	96.6%(197/204)		.929(.000)	780.000 [169.963, 3579.60]	(1.000)
	96.7%(117/121)	96.4%(80/83)			
Bill	93.6%(191/204)		.788(.000)	124.000 [38.038, 404.227]	(.581)
	97.0%(160/165)	79.5%(31/39)			
Sally	92.1%(188/204)		.803(.000)	112.000 [38.652, 324.533]	(.454)
	93.3%(140/150)	88.9%(48/54)			

Table 11 Agreement Rates by Subject.

Category	True Response		Kappa k(p-value)	Odds Ratio [95%CI]	McNemar (p-value)
	True Positive Sensitivity	True Negative Specificity			
Bathroom	92.0%(218/237)		.713(.000)	117.500 [32.282, 427.673]	(.004)
	98.4%(188/191)	65.2%(30/46)			
Entrance	95.0%(114/120)		.900(.000)		(.031)
	90.8%(59/65)	100%(55/55)			
Kitchen	94.5%(111/117)		.878(.000)	505.600 [56.814, 4499.43]	(.219)
	94.0%(79/84)	97.0%(32/33)			
Moving around	95.1%(97/102)		.899(.000)		(.063)
	91.9%(57/62)	100%(40/40)			
Stairs	100%(36/36)		1.00(.000)		(1.000)
	100%(34/34)	100%(2/2)			

Table 12 Agreement Rates by Problem Area

Problems were identified in 3 home categories and three subject categories. The percentage of correctly identified problems within each category was higher than 90% across all categories (Table 10, Table 11). All Kappa coefficients also were larger than .70 and all Odds Ratios were big enough, saying that the agreement rates between two assessment methods were very high across all home and subject categories. And all p-values of the McNemar test showed that there was not any tendency that identifies problems falsely either in the positive or in the negative way.

Five problem areas were evaluated across nine cases, which are cross matched by three houses and three imaginary subjects. These problem areas were getting in/out of the home entrance, getting up/down interior stairs, moving around the house, using the bathroom, and using the kitchen. As for sensitivity, the percentage of correctly identified problems within each area category was more than 92% and the correct identification rate at getting up/down interior stairs was 100%. Specificities at three areas were 100% and only one negative agreement rate involving the "using the bathroom" was notably low, 65.2%. Inversely, a false positive rate for using the bathroom was relatively high, at 34.8%. Therefore, the p-value of McNemar test at using the bathroom was very small, .004. This implied a tendency to incorrectly identify as problematic a task that was otherwise identified as non-problematic.

6.5 Discussion

This study showed the overall high agreement rate of 94.1% and reported high sensitivity and specificity with 95.6% and 90.3% respectively. These results suggest that the VRTS offers an alternative and efficient tool that can be used by home modification specialists to provide the accessibility assessment for home modification without the need to perform an on-site assessment.

6.5.1 Comparison with Two Previous Studies

The data from this study compare favorably with the results previously reported for the Comprehensive Assessment Survey Protocol for Aging Residents (CASPAR), a remote, paper and pencil assessment protocol [7]. They reported 74.0% sensitivity for problems identified and

92.8% specificity. And the telerehabilitation system using the telephone line based videoconferencing system reported the overall true response rate of 87.1% with sensitivity (86.4%) and specificity (88.2%) of the remote instrument[11].

The VRTS provides specialists with three-dimensional views of the physical environment and photos oriented with a 3D model, which gives specialists the opportunity to better figure out the environment and to more easily measure the physical 3D dimension. These features might contribute to the improved performance of this study. This study took advantage of instruments developed by previous studies such as the CASPAR and tried to overcome the limitations of those studies, such as inaccurate measurements.

6.5.2 Agreement Rates by Individual Task

Category	True Response		Kappa *k*(p-value)	Odds Ratio [95%CI]	McNemar (p-value)
	True Positive Sensitivity	True Negative Specificity			
A01	83.3%(10/12)		.636(.018)	For cohort VRTS = 0 4.5[1.3, 15.27]	(.500)
	77.8%(7/9)	100%(3/3)			
A06	87.2%(34/39)		.253(018)	For cohort VRTS = 0 7.6[3.3, 17.2]	(.063)
	86.8%(33/38)	100%(1/1)			
D05	86.6%(13/15)		.595(.012)	For cohort VRTS = 1 .15[.04, .55]	(.500)
	100%(2/2)	84.6%(11/13)			
F01	88.9%(8/9)		.069(.047)	For cohort VRTS = 0 2.00[.50, 7.99]	(1.000)
	50.0%(1/2)	100%(7/7)			

Table 13 Agreement Rates by Task

In this study, 42 tasks were evaluated across nine cases and five problem areas. The number of assessments per each task varied from 3 to 39, and, overall, 612 task assessments were performed for three houses and three subjects. There was 100% agreement on 26 of 42 tasks. A false assessment was detected only on 16 tasks. I chose four tasks for examples:

A01:Having enough space to build a ramp, A06:Going through the entry door, D05: Reaching or using toilet paper, and F01: Maneuvering space at one of the cabinets. The agreement rates of these tasks were recorded in Table 13.

Although these sample tasks have relatively large numbers of sample size, the sample size was still rather small, and the calculated Kappa coefficients were low and inconsistent. Moreover, p-values of Kappa coefficients failed to guarantee statistical significance. Odds rates also showed low level confidence intervals that could include “1”. This means that there is no significant evidence to support the agreements between assessments by two different methods. Therefore, in order to determine which tasks have high agreement, we need to widen the study area to include more diverse houses and clients.

6.5.3 False Identifications

We had 19 false positive assessments and 17 false negative assessments among a total of 612 task assessments as we can see the list of misidentified tasks at Table 14. False positive identification rate was 4.4%(19/436) and false negative rate was 9.7%(17/176). While the false negative assessments, resulting from missed identification of problems, can directly influence the capability to identify problems correctly, the false positive assessments, which identify problems that do not exist, actually have positive potential for safety. In this study, more than half of the misidentifications were false positives. Although falsely identifying a problem that does not exist might result in financial loss, such mistakes could also be helpful. However, misidentification of existing problems could result in hazardous consequences.

As we can see at the result section 6.4.2.Agrrement Rates by House, Subject, and Area, overall, the agreement rates were high across three houses, three subjects, and five areas. But we can figure out that some parts had relatively low specificities: The true negative rate (specificity) for the first house was 79.5%(31/39), the specificity for Bill was 79.5%(31/39), and the specificity for the bathroom was 65.2%(30/46).

(unit : inch)

TASK	AREA	HOUSE	SUBJECT	CIP	VRTS	FALSE
Having enough space to build a ramp.	Entrance	3rd	ALFRED		Checked	Positive
Having enough space to build a ramp.	Entrance	3rd	BILL		Checked	Positive
Reaching the entrance from the street	Entrance	1st	BILL		Checked	Positive
Going through the entry door.	Entrance	2nd	SALLY		Checked	Positive
Going through the entry door.	Entrance	2nd	SALLY		Checked	Positive
Going through study room doorway	Hallway	2nd	SALLY		Checked	Positive
Going through family room doorway.	Hallway	2nd	SALLY		Checked	Positive
Going through an interior doorway.	Studyrm	2nd	SALLY		Checked	Positive
Going over the threshold at the door.	Entrance	2nd	SALLY		Checked	Positive
Maneuvering at a door to open it.	Hallway	3rd	BILL		Checked	Positive
Turning into a hallway from a room.	Studyrm	2nd	SALLY		Checked	Positive
Reaching or using toilet paper.	Bathroom	1st	BILL	Checked		Negative
Reaching or using toilet paper.	Bathroom	1st	SALLY	Checked		Negative
Flushing a toilet.	Bathroom	1st	ALFRED	Checked		Negative
Flushing a toilet.	Bathroom	1st	ALFRED	Checked		Negative
Turning into a hallway from a room.	Bathroom	1st	ALFRED	Checked		Negative
Turning into a hallway from a room.	Bathroom	1st	BILL	Checked		Negative
Turning into a hallway from a room.	Bathroom	1st	SALLY	Checked		Negative
Maneuvering space at a bathtub.	Bathroom	1st	ALFRED		Checked	Positive
Maneuvering space at a bathtub.	Bathroom	1st	BILL		Checked	Positive
Maneuvering space at a bathtub.	Bathroom	1st	SALLY		Checked	Positive
Reaching the faucet in a bathtub.	Bathroom	1st	BILL	Checked		Negative
Reaching the faucet in a bathroom sink.	Bathroom	2nd	BILL	Checked		Negative
Reaching the faucet in a bathroom sink.	Bathroom	3rd	BILL	Checked		Negative
Reaching the faucet in a bathroom sink.	Bathroom	3rd	SALLY	Checked		Negative
Turning the faucet on/off in a sink.	Bathroom	2nd	BILL	Checked		Negative
Turning the faucet on/off in a sink.	Bathroom	3rd	BILL	Checked		Negative
Turning the faucet on/off in a sink.	Bathroom	3rd	SALLY	Checked		Negative
Getting items from a cabinet or shelf.	Bathroom	2nd	BILL	Checked		Negative
Getting items from a cabinet or shelf.	Bathroom	2nd	SALLY	Checked		Negative
Maneuvering space at one of cabinets.	Kitchen	2nd	SALLY	Checked		Negative
Maneuvering space at one of cabinets.	Kitchen	1st	BILL		Checked	Positive
Maneuvering space at one of cabinets.	Kitchen	1st	SALLY		Checked	Positive
Taking items out of lower cabinets.	Kitchen	2nd	ALFRED		Checked	Positive
Taking items out of lower cabinets.	Kitchen	3rd	ALFRED		Checked	Positive
Maneuvering space at electric range.	Kitchen	1st	SALLY		Checked	Positive

Table 14 the list of falsely identified tasks

Seven tasks of first house were not checked to be problematic by the VRTS evaluation when they were check to be problematic by the CIP evaluation. False negative rate for the first house was 20.5% (8/39). And all of them were at the problem are of “bathroom”. 16 tasks of bathroom were falsely identified to be non-problematic and the false negative rate was 34.8% (16/36). This result showed that the bathroom of the first house had many negative misdiagnoses. They reflect that this house has two small bathrooms. While the problem area of “using the bathroom” had 20 tasks to be evaluated in the evaluation form, other areas had 7 to 14 tasks. The fact that the bathroom had more tasks could be a cause of its high chance to be falsely identified.

Bill had 13 false identification – 8 false negative identifications (20.5%(8/39)) and 5 false positive identifications (3.0%(5/165)). And Sally had 16 false identification – 6 false negative identifications (11.1%(6/54)) and 10 false positive identifications (6.7%(10/150)). Because even if Bill had less false identifications than Sally, he had a relatively large number of false negative identifications, he had to have a relatively low specificity, 79.5%(31/39). This fact could means that the architect with the CIP was more conservative in interpreting the functional ability of Bill and task features than the other architect with VRTS. Bill’s situation was created to be a 16 year old boy with a diagnosis of spastic quadriplegia cerebral palsy. And he was supposed to use power wheelchair. His imaginary situation could make a little different interpretation about his dexterity and his wheelchair’s safe and dynamic width between two architects. For example, the task of “turning the faucet on/off in a sink” in the bathroom of first and second house was diagnosed differently by two evaluators for Bill.

As above false identification data says, some misidentifications could result not from data collection methods themselves, but rather from differences in interpretation of the features of subject and tasks by the two architects. For example, the task of maneuvering space at one of the cabinets in the kitchen was differently interpreted by two evaluators. While one architect interpreted that a wheelchair user could perform this task by parking his/her wheelchair side by side next to the cabinet, another architect judged that the client using a wheelchair could not access the cabinet because the leg part of the wheelchair would interfere with the lower part of the cabinet.

In order to prevent the misidentification due to different interpretation, we need to set up the rigid criteria to interpret the ambiguous situations and tasks more clearly in the further study. Especially, this study's result requires us to pay more attention on the tasks of the problem area of "using the bathroom" It would improve the research results.

6.5.4 Imaginary Subjects

We created imaginary subjects in order to more accurately compare the two evaluation methods for three houses. In an actual application, the evaluation results would depend on the client's information. For example, the client might provide the information that her hallway presented no problems and thus did not need to be evaluated. But her opinion might not be correct and might then prevent the assessment of a potentially problematic area. Conversely, too much pre-assessment information could threaten the objective ability of this research to compare the assessments by two methods. Therefore, in order to evaluate the new method objectively, we decided to create imaginary subjects instead of using an actual client. In this experimental trial, although the evaluators received the simple survey form that included the client's diagnosis, they had no way to contact the client for more information. Therefore, they contacted the investigator if they wanted to confer with the client. The investigator answered and clarified situations of the imaginary subjects so that any misunderstandings between the two evaluators could be eliminated and the evaluation bias from different understandings of the subject's situation could be reduced. If we were using actual clients' information, the evaluator using the CIP method would be able to visit and interview the client, but the evaluator using the VRTS could only contact the client via telephone or mail. This discrepancy could also threaten the internal validity of the research.

In this study, while the evaluator using the conventional method could perform the on-site investigation and call back anytime to question the house owners/occupants about the built environment, the evaluator using remote protocol could not contact the owner /occupant. Therefore the VRTS evaluator was able to address questions about the built environment to the investigator who analyzed the photos in detail and made 3D models and to the student assistant who visited the house and photographed and sketched the floor plan. They answered the questions to the best of their abilities. But in the actual application, the service provider using the VRTS could contact the house owner/occupant via telephone or video conferencing system to get more information about the built environment. It is expected that when VRTS is implemented in a real world situation, both the person who administers the assessment and the client who is assessed will be contacted with questions that arise from analysis of data in VRTS and will be part of the assessment decision process just as they would be in a conventional on-site assessment.

6.5.5 Accuracy of Reconstructed 3D Models

In order to demonstrate the accuracy of the constructed 3D models, I investigated the accuracy level of the actual physical objects in the reconstructed 3D models**.**

When the 3D model was created, the accuracy of each model was evaluated by comparing the dimension of the norm objects with their measurements in the model. All deviations between the real dimensions and measurements in each 3D model of the norm objects were within 1 inch when we constructed the 3D models. Therefore we proceeded to the VRTS evaluation procedure using these reconstructed 3D models of the target problem areas.

After the VRTS evaluation was conducted, I analyzed again the accuracy by comparing the real objects' measurements between two methods in order to confirm the accuracy of the models. I compared two measurements of a dimension in each of 18 problem areas between in 3D models and in real spaces. As we can see at Table 15, this retrospective analysis also showed that the deviations between measurements in the model and by on-site tape measure were within tolerable level, 1 inch or so.

(unit:inch)

House	Area	Object	On-site	3D model	Deviation
1st house	Back entrance	width of the door	29.750	29.437	0.313
	1st bathroom	width of bathtub	30.000	29.962	0.038
	2nd bathroom	width between walls	35.000	34.935	0.065
	hallway	width of the hallway	40.250	40.850	0.600
	kitchen	width of the door to back porch	29.750	30.258	0.508
	stairs	width of the stairway	36.000	36.881	0.881
2nd house	Back entrance	length of left side edge of the top stair	66.000	65.682	0.318
	hallway	width of the doorway to family room	28.000	27.061	0.939
	Kitchen	width of the doorway from study room	32.000	31.999	0.001
	powder room	wall to wall width of the powder room	32.000	31.219	0.781
	Side Entrance	width of a stair	84.000	83.192	0.808
	Study room	width of the doorway to the kitchen	32.000	32.714	0.714
3rd house	Back entrance	width of a door	32.000	31.890	0.110
	1st bathroom	wall to wall	32.000	31.141	0.859
	2nd bathroom	width of a door	22.000	22.188	0.188
	hallway	width of hallway	36.750	36.800	0.050
	kitchen	width of a door	32.000	32.518	0.518
	stairs	width of stairway	34.000	34.029	0.029

Table 15 the measurement between in 3D models and by on-site tape measure

6.5.6 Time for Constructing 3D Models

1st house		2nd house		3rd house	
Back entrance	2.5 hrs	Back entrance	1.0 hr	Back entrance	1.0 hr
1st bathroom	1.5 hrs	hallway	2.5 hrs	1st bathroom	1.5 hrs
2nd bathroom	2.0 hrs	Kitchen	2.5 hrs	2nd bathroom	2.0 hrs
hallway	3.5 hrs	powder room	2.0 hrs	Hallway	2.5 hrs
Kitchen	2.5 hrs	Side Entrance	2.0 hrs	Kitchen	2.0 hrs
Stairs	1.5 hrs	Study room	1.5 hrs	Stairs	3.0 hrs
Total	13.5 hrs	Total	11.5 hrs	Total	
Average	2.25 hrs	Average	1.92 hrs	Average	2.00 hrs
Average					2.05 hrs

Table 16 the measurement between in 3D models and by on-site tape measure

For the VRTS, It is a most import procedure to construct 3D model. The analysis of consumed time could provide us some estimation on cost-effectiveness even if we could not analyze the exact cost. It took 1 to 3 hours to construct a 3D model of a problem area. The more complex the structure, the more time consumed. The back entrances of second and third house were simple. Only three photos were used to construct 3D models and it took one hour. The hallway of the first house was T-shaped and had many doorways as we can see at Figure 33. It required 14 photos and 3.5 hours to construct a model. On average, we estimate that 2 hours are needed to construct the 3D model of a single area and 12 hours for a whole house.

Although the 3D reconstruction with 2D photos requires technician's time consuming efforts, we can still value the critical advantage of the VRTS because affordability of service delivery is more important than cost effectiveness for clients in under-served areas. In particular, we can see that the greater the geographical distance, the greater the benefits of the VRTS method.

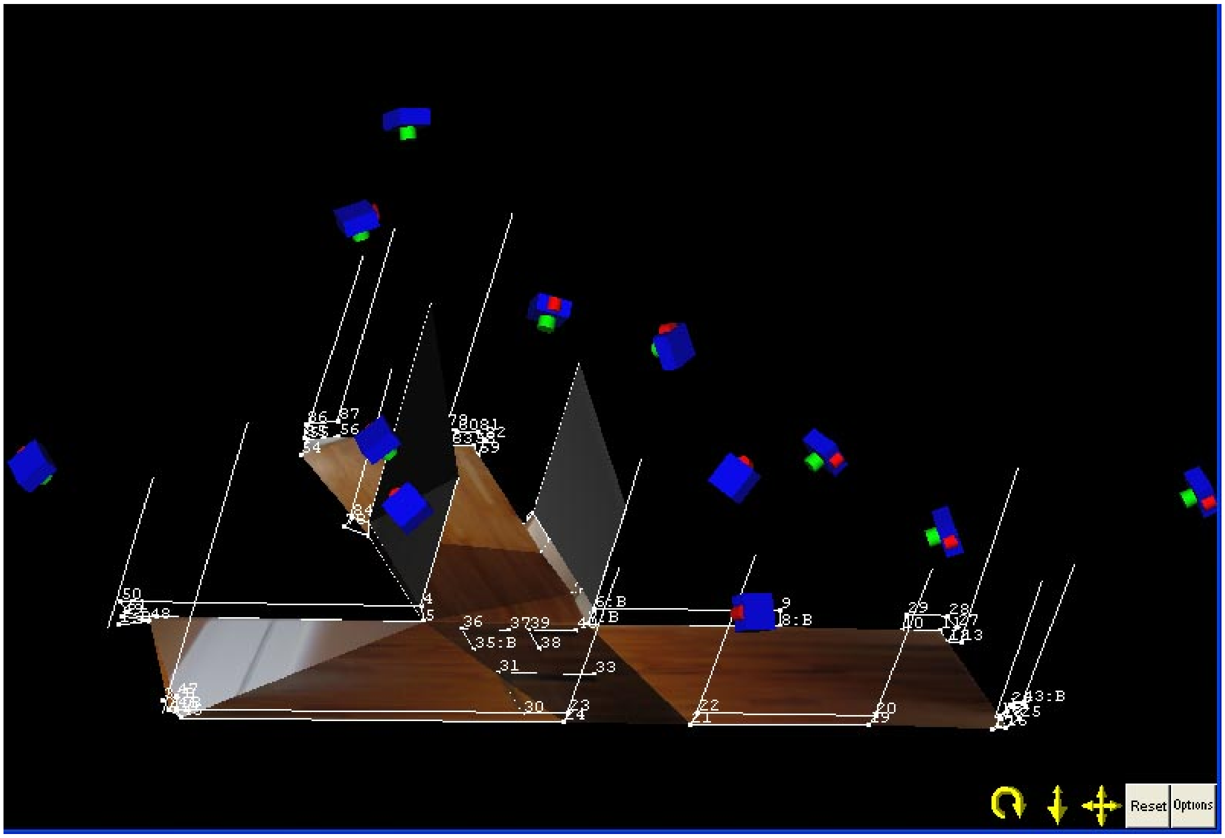


Figure 33 3D model of the hallway of first house

6.5.7 Generalizabiliy

We evaluated the houses of three clients who requested the accessibility assessment to the architect firm, Lynch & Associates. One was a ranch style house, another one was a multi-level house, and third one was a 3 story Victorian style house. We created three exemplar subjects who had different diagnoses and who used different wheeled mobility devices. We tried different situations in order to test the external validity. But the sample size of houses and subjects was small. But this study showed that our developed system might be applied to other underserved area including geographically availability and expert's availability and to workspace area and elders and people with disability other than mobility impairments and further generations and future era with more advanced technologoies.

However, in order to generalize this study more, we need to expand our study into more diverse kinds of house, diagnosis and wheeled mobility devices with larger sample size, so that our developed system could be applied to other underserved area including geographically availability and expert's availability and to workspace area and elders and people with disability other than mobility impairments and further generations and future era with more advanced technologoies.

6.6 Conclusion

Three actual houses were evaluated which were matched with three imaginary subjects. Thus field evaluations for these nine cases were performed. Each case was evaluated across six problem areas by two architects via the Conventional In-Person method and the Virtual Reality Telerehabilitation System. The analysis of 612 pair assessments showed a high agreement between assessments by the two methods. Findings suggest that the VRTS assessments have the potential to enable specialists to assess potential accessibility problems in built environments regardless of the location of the client, home, or specialist.

Most importantly, this system proved that Virtual Reality and 3D reconstruction technology can provide an effective means to investigate the architectural features of a built environment without visiting the site. Even if 3D reconstruction requires cumbersome trials and comprehensive manipulation of the software and the involved photographing process, the protocol could be improved continuously by adapting state-of-the-science technologies such as video-based 3D modeling and laser scanning.

This system can become an efficient tool for the service provider and can provide expert service to underserved clients thatwould otherwise be unavailable. As this study verified the value of the Virtual Reality Telerehabilitation System for analyzing accessibility of the physical environment, the developed Virtual Reality Telerehabilitation System could improve rehabilitation outcomes by making accessibility assessments and modifications available to a larger portion of the population of wheelchair users.

CHAPTER 7: SUMMARY AND CONCLUSION

7.1 Remote Accessibility Assessment System

Home modification has come to be recognized as an important intervention strategy to manage health care conditions, maintain or improve functioning, ensure safety, and reduce the wheelchair user's dependency on others. Effective home modification requires consultation with skilled professionals capable of assessing the home environment and identifying changes necessary to meet the wheelchair user's needs. While there are many building and remodeling contractors able to perform the modifications, the availability of skilled professionals with experience in home modifications for accessibility is limited. Providing services in rural areas is particularly difficult. Such service requires lengthy travel times that increase cost and consume the limited time of skilled professionals. Even if a specialist is willing to travel a long distance, travel cost is too high relative to the fee for modification. And even a specialist couldn't accurately assess the environment's accessibility without visiting the site. A system that enables accurate remote assessments would be an important tool to improve our ability to perform home assessments more easily and at decreased cost.

Some developmental work has been done using a remote accessibility assessment system in rural or under-served areas. A team of clinicians at the Shepherd Center (Atlanta, Georgia) performed a case study of remote home modification evaluation using a videoconference system with a video telephone. Another effort was undertaken by Extended Home Living Services in Wheeling, Illinois. which developed a remote assessment protocol using a survey instrument, the

Comprehensive Assessment Survey Process for Aging Residents (CASPAR^{TM}). Results of these two studies suggested that remote telerehabilitation assessments had the potential to enable specialists to diagnose potential accessibility problems in home environments and to prescribe appropriate modifications regardless of the location of the client, home, or specialist. But, both of these studies are limited in that the dimensions obtained are not sufficient for use in specifying modifications. Both methods depend on dimensions obtained by the client, using a tape measure.

The use of virtual reality technology and telerehabilitation concepts to assess the home built environments of persons with severe mobility impairments was recently proposed by University of Pittsburgh researchers. The Virtual Reality Telerehabilitation System (VRTS) described here was developed as part of the proposed project.

7.2 Virtual Reality Telerehabilitation System for accessibility analysis of built environment

A system that enables accurate remote assessments would be an important tool to improve our ability to perform home assessments more easily and at decreased cost. Therefore, this study addressed the development of a remote accessibility assessment system using the concept of telerehabilitation and the virtual reality technologies and their effects. This system used commercial software to construct 3D virtualized environments from photographs. Custom screening algorithms and instruments for analyzing accessibility have been developed.

Characteristics of the camera and the 3D reconstruction program significantly affect the overall reliability of the system. In this study, we performed two reliability analyses on the hardware and software components: 1) Verification that the commercial software, Photomodeler Pro, can construct sufficiently accurate 3D models by analyzing the accuracy of the dimensional measurements in the virtualized environment; 2) comparison of dimensional measurements with four camera types. Based on these two analyses, we were able to specify a consumer level digital camera and the Photomodeler Pro software for this system. As the third phase, we tested the system in an actual environment to evaluate its ability to assess the accessibility of a wheelchair user's typical built environment. This feasibility test showed our system could assess the accessibility correctly, thus validating its potential value.

Through these pilot studies, algorithms for constructing 3D models of wheelchair users' home environments and for assessing the environments' accessibility were developed, including the development of several new tools, such as a guidelines book on how to take pictures, a survey form, a measurement form, and a evaluation form. As the last phase of this study, we performed field trials and evaluated the developed system's capability, as compared to that of the CIP method, in assessing the accessibility of the wheelchair user's built environment.

Field trials showed the overall high agreement rate of 94.1% and reported high sensitivity and specificity with 95.6% and 90.3% respectively. This result suggests that the VRTS offers an alternative and efficient tool that can be used by home modification specialists to provide the accessibility assessment for home modification without having to perform on-site assessment themselves.

The data from this study compare favorably with 74.0% sensitivity for problems identified and 92.8% specificity that were previously reported for the Comprehensive Assessment Survey Protocol for Aging Residents (CASPAR), a remote, paper and pencil assessment protocol [7]. And the telerehabilitation system using the telephone line based videoconferncing system reported the overall true response rate of 87.1% with sensitivity (86.4%) and the specificity (88.2%) of the remote instrument [11].

The VRTS provides the specialists three-dimensional views of physical environment and photos oriented with 3D model, which gives specialists the opportunity to be able to figure out the environment better and measure easily the physical 3D dimension. These features might contribute to the improved performance of this study. And this study took advantages of instruments, developed by these previous studies, like the CARSPAR and tried to overcome the limitations of those study such as inaccurate measurement.

7.3 Limitation

Although we could demonstrate the potential value of the VRTS through field trials projects, the method has some limitations.

First, even with a developed guidebook, it is still a challenge for a novice to take appropriate 2D pictures for the 3D reconstruction of an interior built environment.

Secondly, the VRTS cannot provide sufficient and effective communication between the consumer and service provider.

Thirdly, learning to construct 3D models with Photogrammetry software remains a time consuming job. However, as technologies evolve, becoming easier to use and available at lower cost, we can consider the possibility of automatic 3D reconstruction technologies using a camcorder or laser scanner.

Lastly, we could not conduct the architect's evaluation for large sample of built environments via the Conventional In-Person method because the architect's fee is too expensive for the pilot study for a feasibility test. This issue restricted this study could evaluate only three houses. A comprehensive field evaluation with diverse houses and subjects need to be designed and performed to address this limitation.

7.4 Future Work

In order to overcome insufficient communication between client and service provider, we are developing an on-line version of the VRTS. . The Online-VRTS provides a means for individuals with severe mobility impairments to access a Multimedia Remote Assessment Support System (MRASS) for accessibility assessment of their living environment, in which preliminary information from the customer including 2D photos, 3D geometry, and sizes and dimensions of the built environment will be included. This web-based MRASS will enable real-time collaboration among project members (e.g., customer, clinician, counsellor, architect, engineer, and vendor) and facilitate consumer control of interventions. It allows project members to share information, exchange ideas, and retrieve documents.

And in order to resolve the photographing issue, we designed a new photographing protocol, a Videoconferencing and Tele-Imaging System, through which the consumer can video conference with the specialist while photographing the environment. Using this system, the provider will guide the consumer through the picture taking process, thereby ensuring the inclusion of all important features of the environment. Collaborating with assessment experts in real-time, a photographer can capture all architectural features and elements of a home with a camera and laptop computer connected to the Internet via the wireless LAN adapter. An assessment service provider with appropriate expertise can view the consumer's built environment from a remote location and specify the camera position and angle of each photo. With this client-side imaging support we can acquire good 2D photos for the 3D modelling from the remote site. The videoconferencing and remote imaging sub-system will provide high-quality raw data and information for the Online-VRTS system.

Currently, we can construct partial 3D models for each interior parts of the built environment (e.g., sections of living room, kitchen, bathroom and bedroom) with Photomodeler.

But, Photomodeler cannot make a whole 3D model of house. The incomplete and dispersed geometry needs to be integrated to form a complete model to support assessment. Data modelling and transfer protocols will be developed for 3D model construction of the whole construct of the built environment, including real-time model sharing on the web with dynamic bandwidth requirement, and data security and access control to protect customer's privacy. With 3D VR models, a virtual wheelchair can be embedded into the virtual environment, and consumer or clinician can explore the built environment intuitively. Problematic configuration in the built environment can be detected easily and accurately. Parametric models can be generated from the static geometry to aid customer, clinician, architect, and engineer in formulating structural modifications and evaluations.

The study by Han et al. provides good implications to VR accessibility assessment by adapting the automated ADAAG code checking system and simulation of wheelchair maneuvering in the built environment. The Israeli team's study also presented a good tool to enable an optimal fit between the individual and the environmental setting by using Virtual Reality and simulation technology. If the automated ADAAG code checking system and the wheelchair maneuvering simulation system can be integrated in the VRTS, the performance of the system should be improved remarkably.

And lastly, we are considering to develop the video-based 3D reconstruction system, which is much easier to construct accurate 3D models. It should be an automatic system. Then, all we have to do should be to take a video with a digital camcorder.

7.5 Conclusion

We developed a Virtual Reality Telerehability System using the 3D reconstruction technology and performed field trials to assess the value of the developed system. Three actual houses were evaluated with matched by three imaginary subjects. The results of field trials showed high congruence between the assessments by two methods. Findings suggested that the VRTS assessments have the potential to enable specialists to assess potential accessibility problems in built environments regardless of the location of the client, home, or specialist. This study also provided the evidence that a virtual reality telerehabilitation system can be an alternative, cost-effective solution to conventional rehabilitation services.

Especially, this system proved that the Virtual Reality and 3D reconstruction technology can give a good alternative environment to investigate the architectural features of the built environment without visiting. This system will be able to provide an efficient tool to the service provider and give the underserved clients more opportunities that could get the benefits of expert's service. As this study verified the value of the Virtual Reality Telerehabilitation System for analyzing accessibility of the physical environment, the developed Virtual Reality Telerehabilitation System could improve rehabilitation outcomes by making accessibility assessments and modifications available to a larger portion of the population of wheelchair users.

We will improve the system continuously with the state-of-the-science technologies and this progress in this study will provide a means of accessibility assessment for wheelchair users in underserved areas who otherwise would not have access to evaluations of their built environments by professionals. The VRTS can be utilized in both homes and public spaces, and the study shows the potential for applications of virtual reality technology in the area of architectural interior environment, such as in the interior design and home renovation industries.

APPENDIX A

Guidelines for Taking Good Pictures

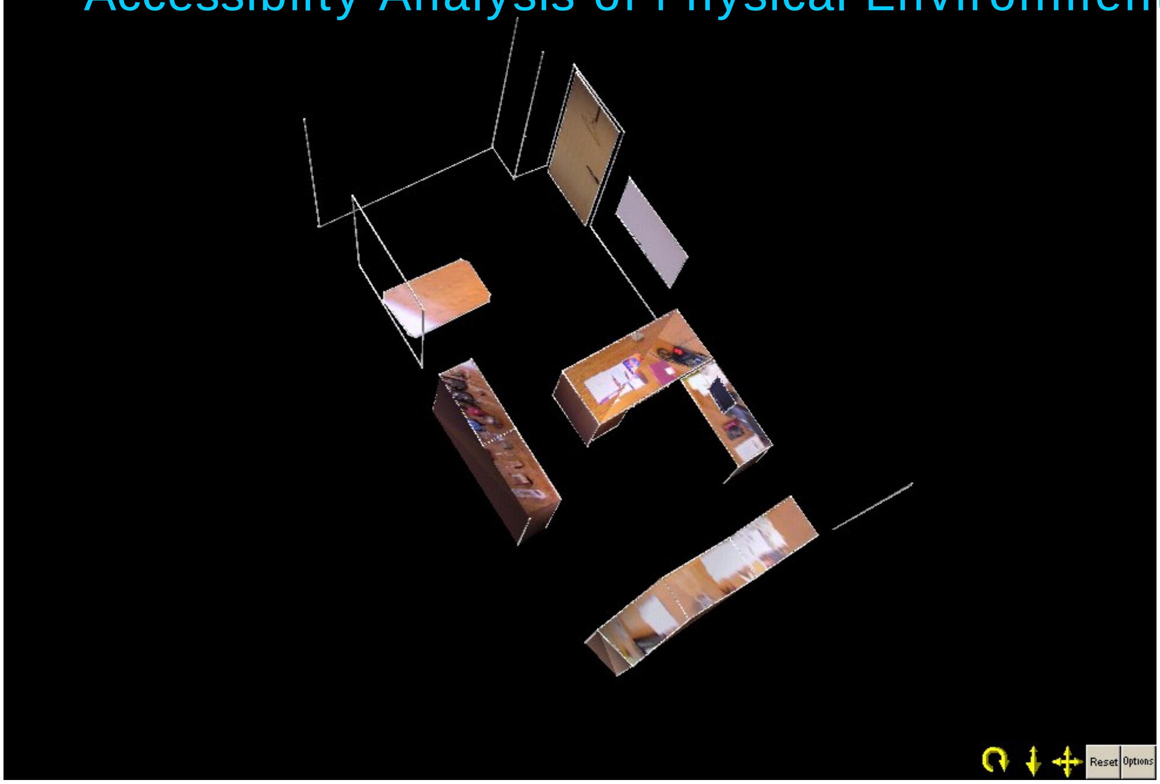
GUIDELINES

For

How to Take Good Pictures

Of

Virtual Reality Telerehabilitation System for Accessibilty Analysis of Physical Environment



Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Science
University of Pittsburgh

Fundamental Rules

1) Photos should be taken at a fixed focal length.

2) Norm objects with known dimensions (to be provided along with camera) should be placed in the middle of each target space.

3) Camera should be placed at the highest possible position with its back as close to the walls and ceiling as possible

4) Photos do not need to include the ceiling.

5) Each photo should include the floor and as many objects on the floor as possible.

6) All points, wall intersection lines, and objects should be included in 2 or more photos.

7) Each photo should contain as many objects within a target space as possible.

8) Each photo should contain two or more adjacent walls and two or more vertical wall intersection lines if possible.

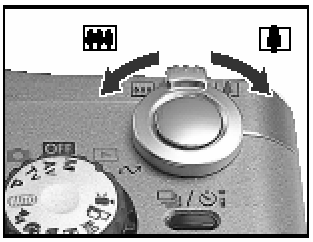
9) Any objects that hide the corner point and/or vertical wall intersection line must be removed.

10) The blinds or curtains must be drawn to block out extra light.

1)Photos should be taken at a fixed focal length.

If you use a digital camera with a zoom lens, you must use one fixed focal length for all your projects. That means that you should set your lens to the wide angle position and should not zoom in.

For example, when using Canon G1 camera, press the Zoom lever toward zoom out (wide angle)



FOCAL LENGTH

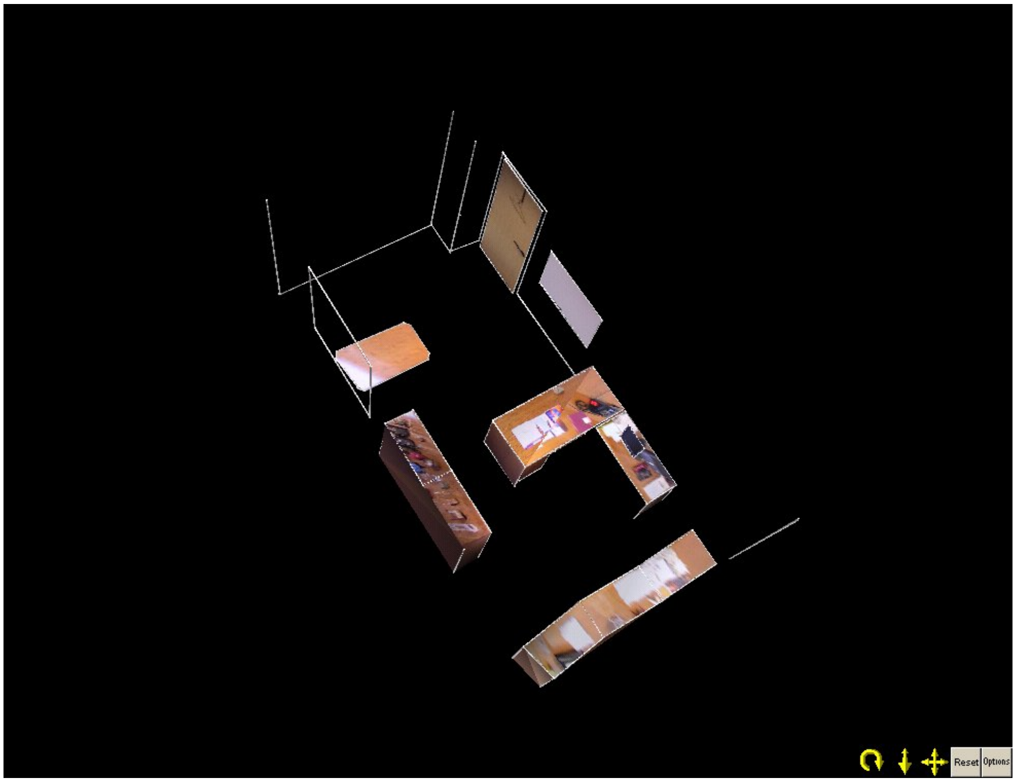
This is the distance (in mm.), in an optical system, from the lens (or primary mirror) to the point where the telescope is in focus (focal point). The longer the focal length of the telescope, generally, the more power it has, the larger the image, and the smaller the field of view.

2)Norm objects with known dimensions (which will be provided along with a camera) should be placed in the middle of each target space.

The 3D modeling process requires one accurately measured distance between two points within a targeted space in order to measure all objects' dimensions in the virtualized model.

Norm objects with known dimensions, such as a carpenter's square, will be provided along with a camera. They can be located at the center area within the targeted space and can be shared by most photos. Some objects with known length, such as letter or A4 size paper, can be placed at the center area of the target space as norm objects .

Below, you can see a sample project of an office room whose 3D model was constructed from 5 photos.



(2-A)

(2-B)

(2-C)

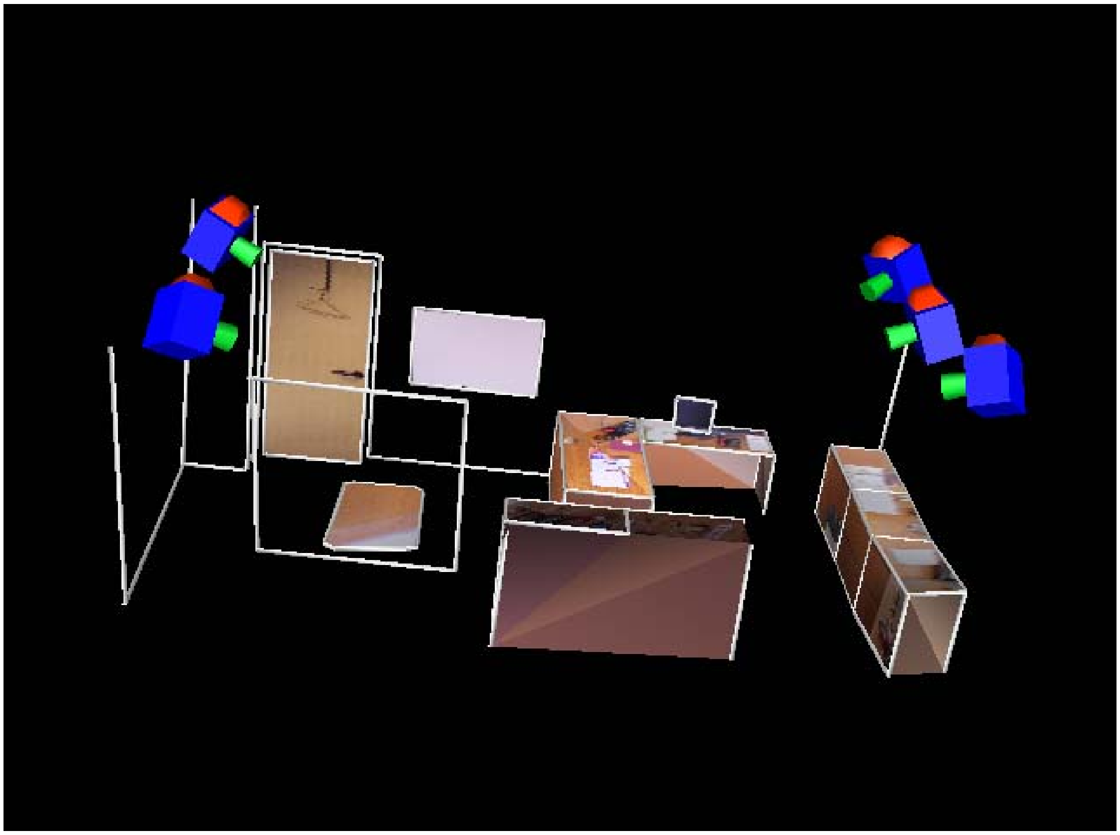
(2-D)

(2-E)

(2-F)

In this sample project, the side edge of the table or a letter size sheet of paper on the table would be a good fiducial measurement to scale all other objects in this virtual office.

3) The camera should be placed at the highest possible position with its back as close to the walls and ceiling as possible.



(3-A)

In order to include more objects in a photo, the camera must be positioned as close to the wall and at the highest site, as can be seen in the above 3D image (3-A).

If we look at the above 3D image carefully, we can see that all of the cameras are set up at the highest positions and that the camera angles are downward.

We can also see that the camera must be positioned as far as possible from the objects so that the greatest number and portion of objects can be included in a photo. Thus the camera needs to be very close to the walls and the ceiling.

4) The photos do not need to include the ceiling.

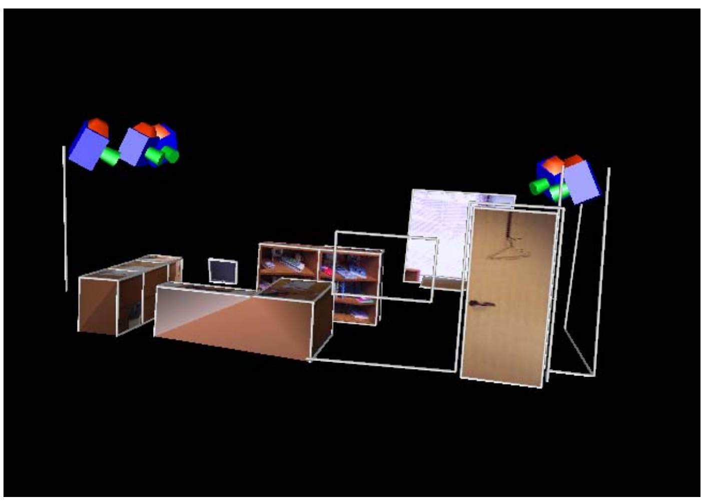
(4-A)

(4-B)

Because we want to construct a 3D model in order to assess the accessibility for wheelchair users, we have to focus on moving lines of wheelchairs.

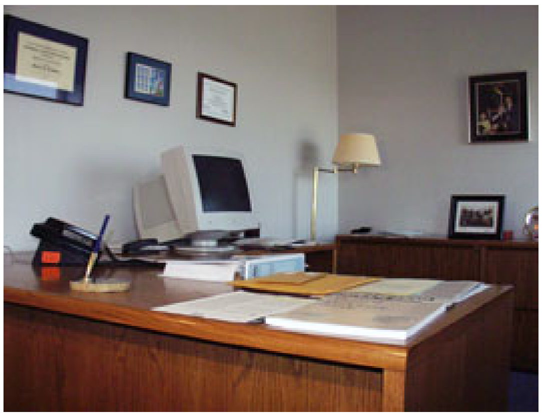
The ceiling need not be included in photos as ceiling lines are not needed in 3D models. For the above example, photo (4-A) has fewer objects than photo (4-B) because it focused upward including unnecessary ceiling lines.

Instead, the camera lens must be focused down towards walls and floor as seen below in 3D image (4-C).



(4-C)

5) Each photo should include the floor and as many objects on the floor as possible.



(5-A)

(5-B)

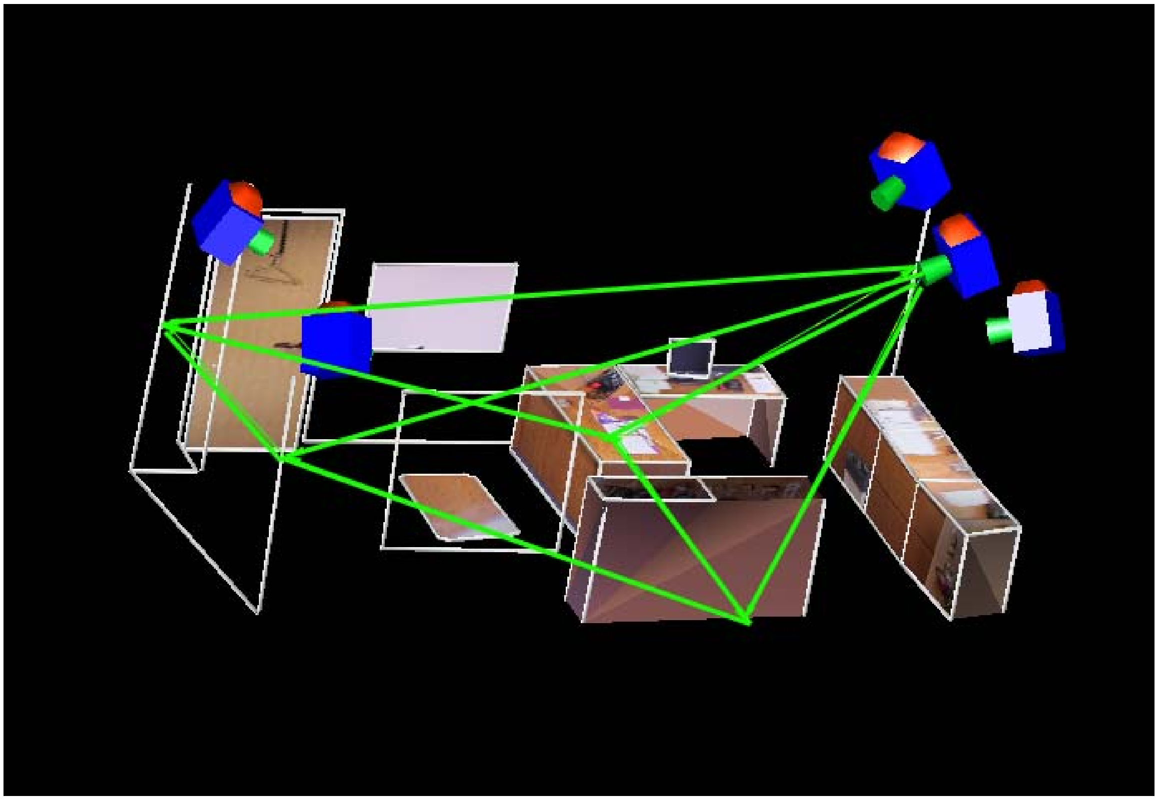
As mentioned at 4), we should include the floor scene instead of the ceiling because we have to focus on moving lines of wheelchairs.

Though photo (5-A) contains two walls, it loses the bottom parts of the desk and walls, which are very important to assess wheelchair accessibility.

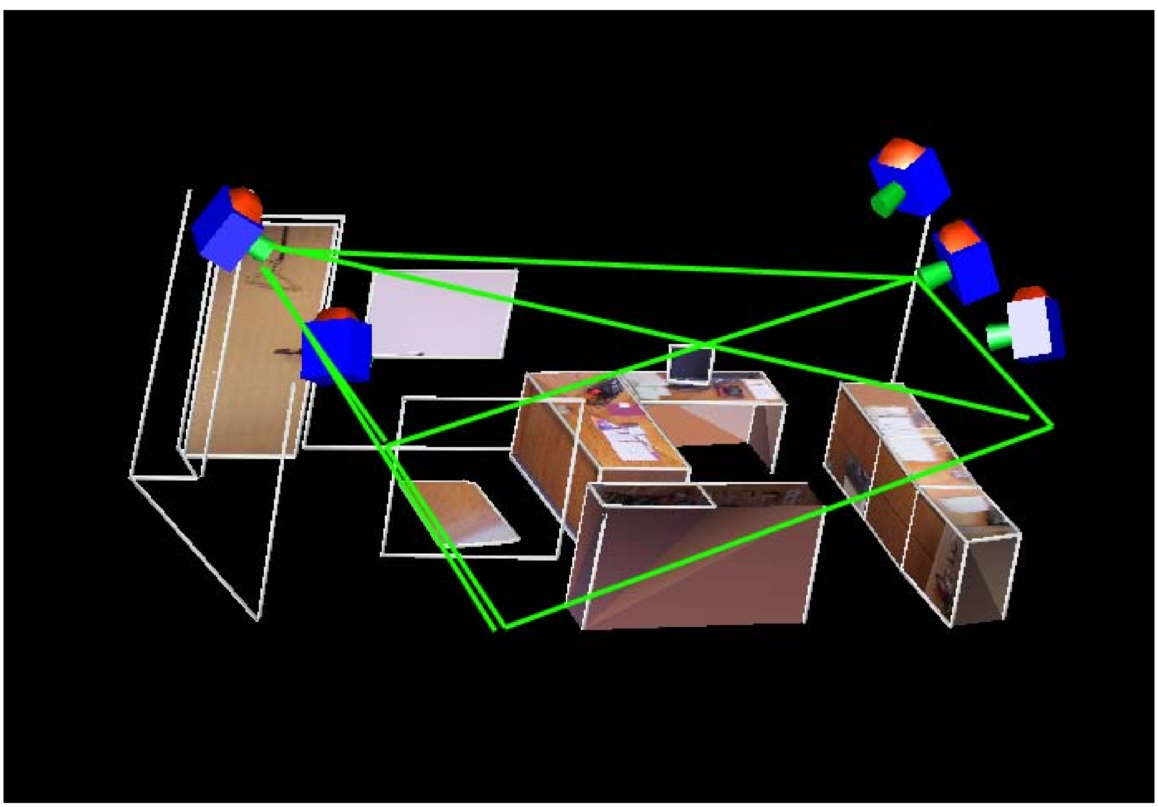
By contrast, in photo (5-B) the focus is downward; thus it includes bottom lines of objects and contains more objects.

Therefore, the camera lens is required to focus downward from the highest corner position towards the floor and lower parts of the walls.

In the 3D projection images below, (5-C) and (5-D), good vertical camera angles can be seen.



(5-C)



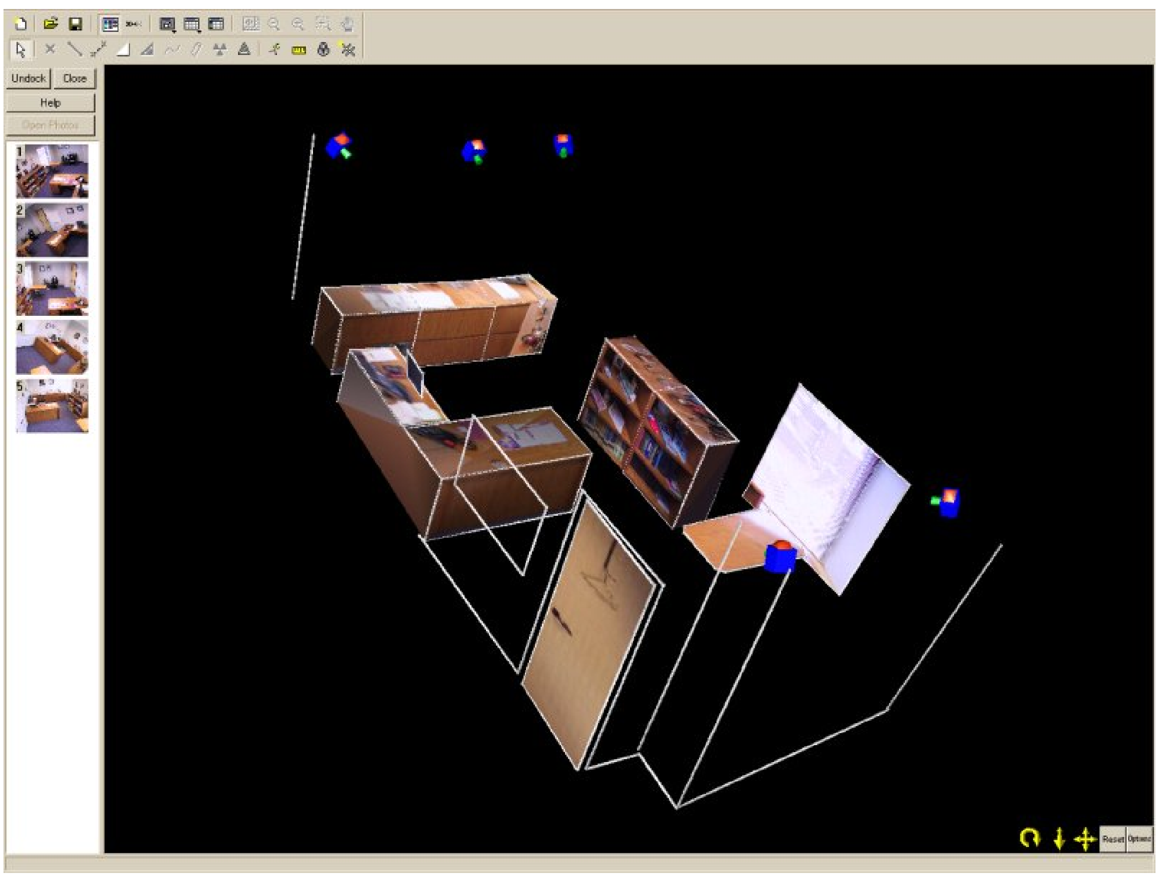
(5-D)

6) All points, wall intersection lines, and objects should be included in 2 or more photos.

In order for points, wall intersection lines, or objects to be validly represented in 3D models, they must be included in 2 or more photos.

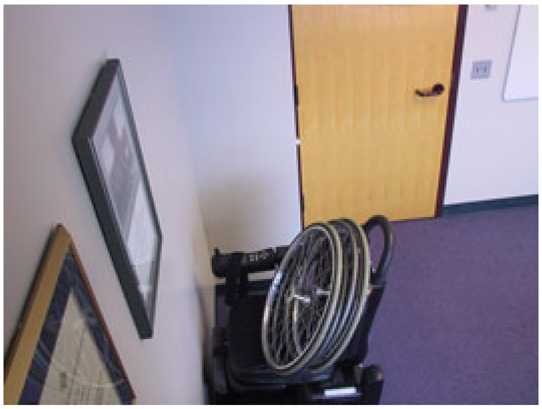
In the sample project (2), we can see a vertical wall intersection line at the right corner only on the photo (2-E). This is why there is no vertical wall intersection line at the right corner in the 3D model (2-A).

Because this wall intersection line is not contained in any other photos, it cannot be calculated into the 3D dimension and oriented as a 3D object. Hence it cannot be seen in a 3D model as shown below in 3D image (6-A).



(6-A)

7) Each photo should contain as many objects within a target space as possible.



(7-A)

(7-B)

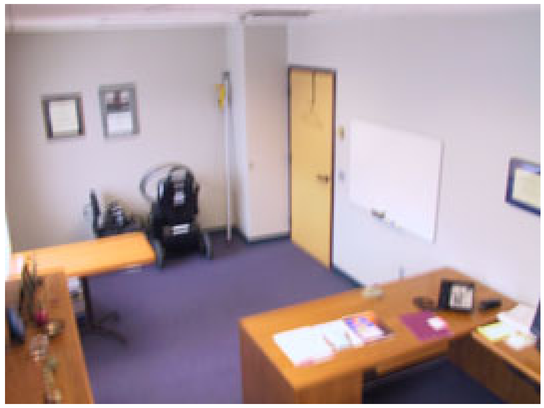
Comparing the above two photos, (7-B) includes more objects than (7-A). Although (7-A) can be used to make a 3D model, it is inefficient because additional photos are required to compensate for objects not included in (7-A) but included in (7-B).

Although the sample project used 5 photos to make a 3D model, 4 photos might suffice if each photo includes more objects than does each of the 5 sample photos. However, if each photo includes fewer objects than does each of the 5 samples, 6 or more photos might be required.

If each photo includes many objects, the group of photos will contain more shared objects, which is beneficial for calculating 3D. However, if the different photos lack shared points, 3D is more difficult to calculate; thus more photos will be required.

8) Each photo should contain two or more adjacent walls and should contain two or more vertical wall intersection lines, if possible.

(8-A)



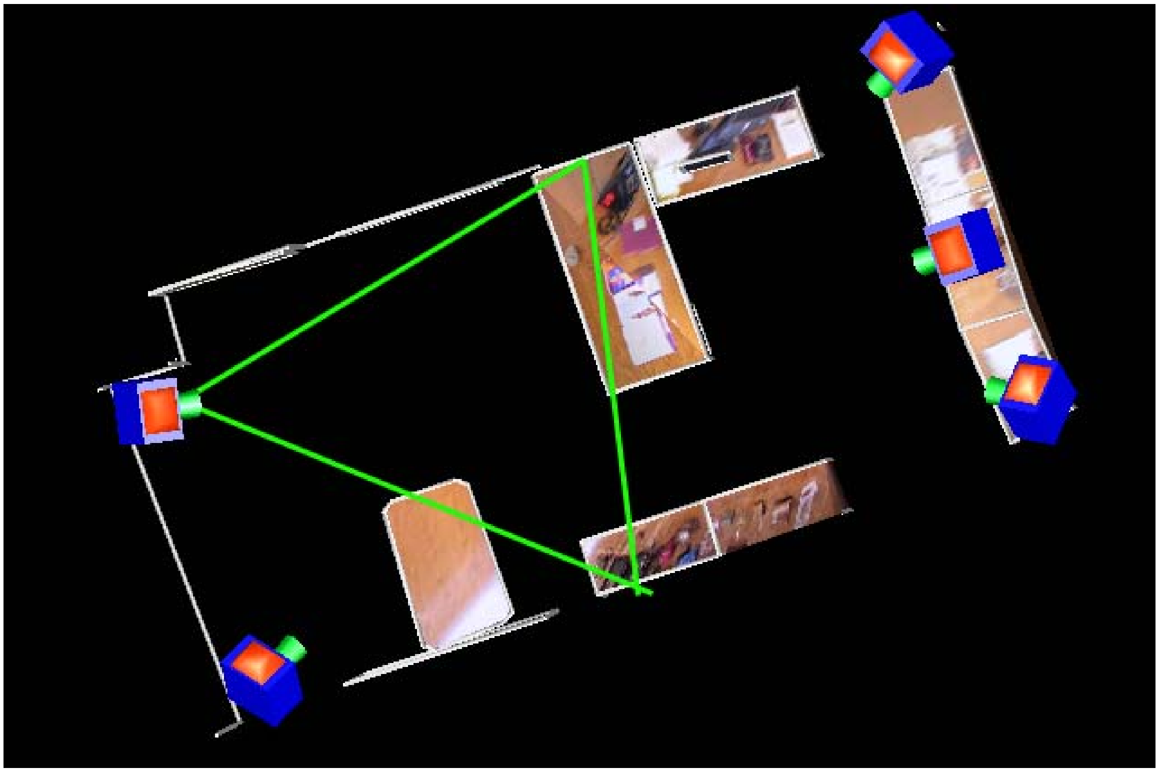
(8-B)

(8-C)

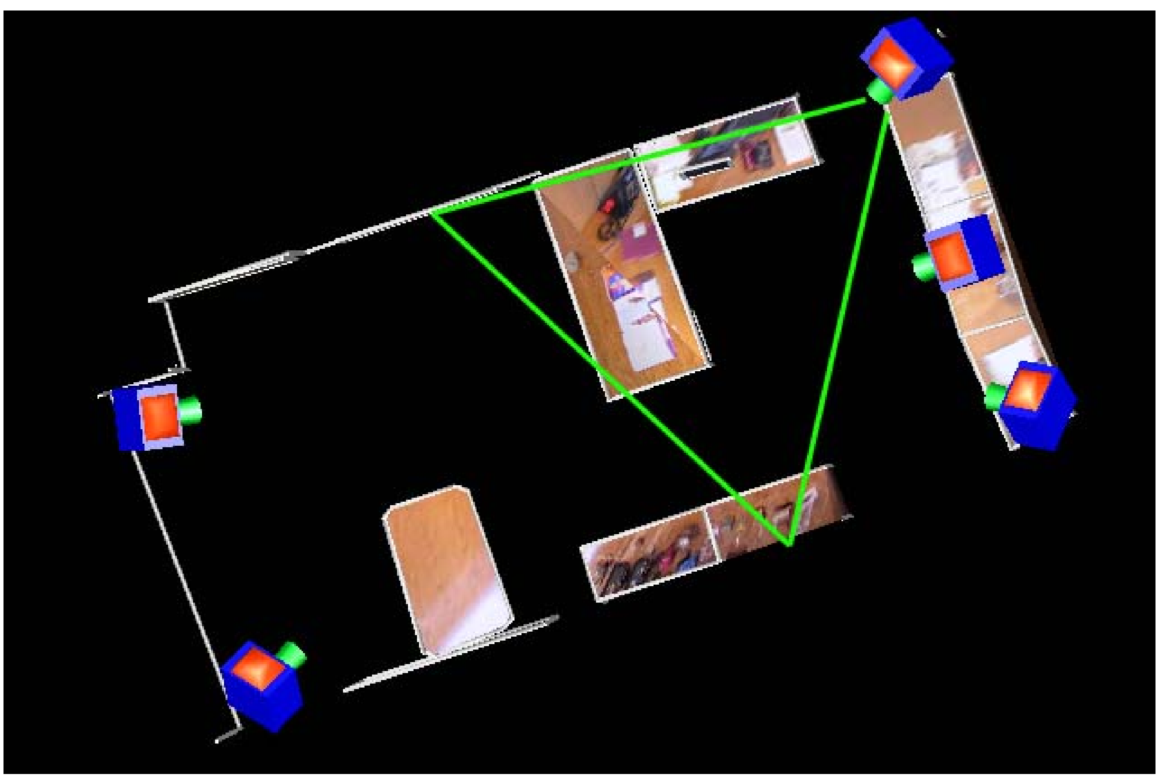
Photo (8-B) is better than photo (8-A) for constructing a 3D model because (8-A) contains just one wall while (8-B) contains two walls.

However, photo (8-C) is much better because it includes 3 walls and 2 vertical wall intersection lines. (8-C) contains more objects than the others and these objects can be shared more easily with other photos.

In the next 3D camera projection images (8-D) and (8-E), we can see expected horizontal camera angles.



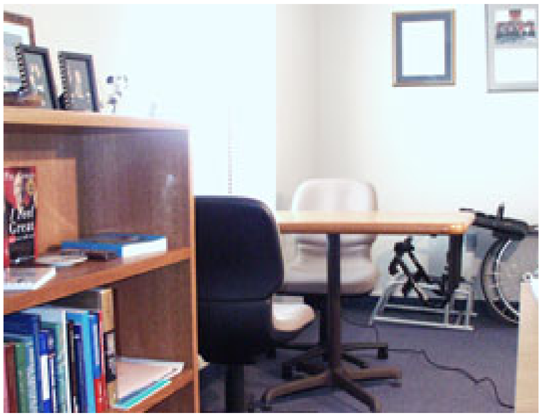
(8-D)



(8-E)

9) Any objects that can hide corner points and/or wall lines must be removed

(9-A)



(9-B)

In photo (9-A), a vertical wall intersection line and an intersection point are hidden by an opened door.

An intersection point and a horizontal wall-floor line are hidden by chairs and a book case in photo (9-B).

If these obstacles can be removed, better pictures can be taken for more efficient construction of a 3D model.

10) The blinds or curtains must be drawn to block out extra light.

(10-A)

Because sunlight can make some parts of the target space too bright, as in the above image (10-A), it is recommended that you close the blinds or curtains and use electric illuminations and a camera flash in order to get good images for 3D modeling.

APPENDIX B

Survey Form for Preliminary Information

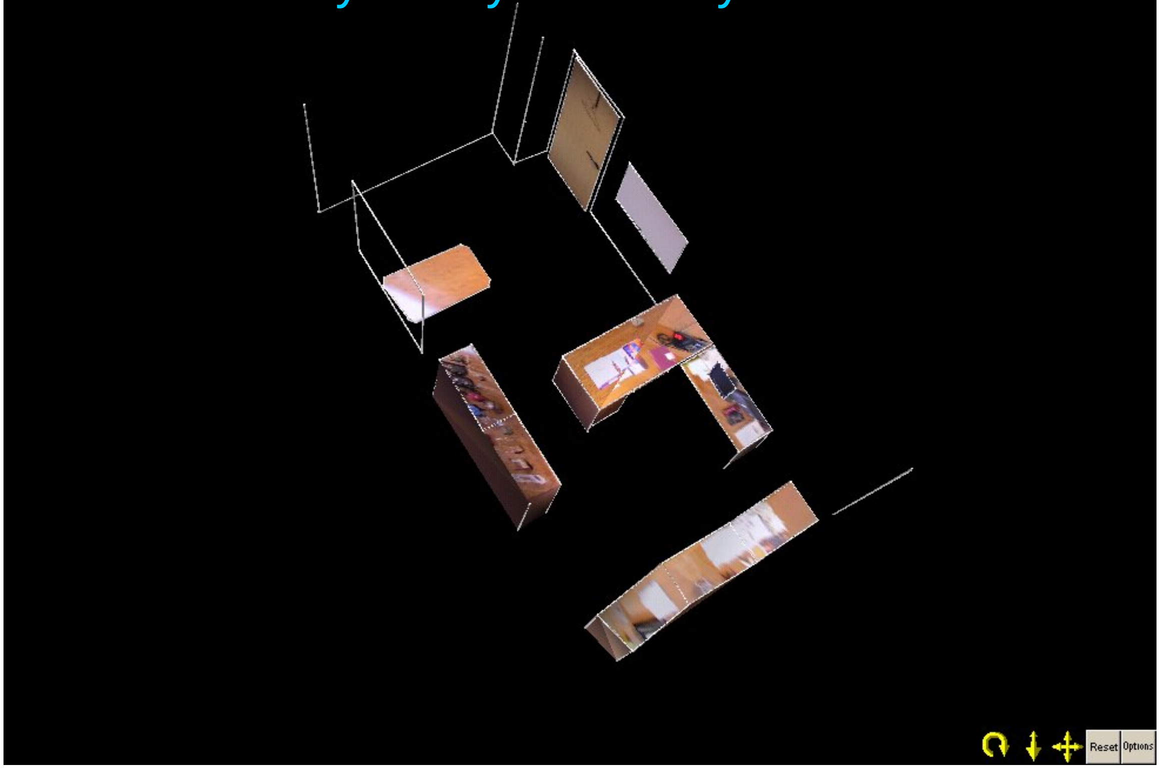
S U R V E Y   F O R M

For

Preliminary Information

Of

Virtual Reality Telerehabilitation System for Accessibilty Analysis of Physical Environment



Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Science
University of Pittsburgh

1. Mobility Aids Information

Mobility Aids Used (check all that apply)

❑ Scooter

Widest Width : ____________

Max. Length : ____________

Seat Height : ____________

❑ Manual Wheelchair

Widest Width : ____________

Max. Length : ____________

Seat Height : ____________

❑ Power Wheelchair

Widest Width : ____________.

Max. Length : ____________.

Seat Height : ____________.

Comments :

____.

____.

____.

____.

____.

2. Physical Environment

A. Entrances to the home.

a) Types of entrances

Check the box which belongs to your home.

- ❑ Front
  - o No step
  - o One step
  - o Two and more steps
  - o Steps with landing
  - o Porch
- ❑ Back
  - o No step
  - o One step
  - o Two and more steps
  - o Steps with landing
  - o Porch
- ❑ Side
  - o No step
  - o One step
  - o Two and more steps
  - o Steps with landing
  - o Porch
- ❑ Garage
  - o No step
  - o One step
  - o Two and more steps
  - o Steps with landing
  - o Porch
- ❑ Other

  ____.

  ____.

b) Problems

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting to any entrance from the street, driveway or sidewalk.
- ❑ Maneuvering any entry door.
- ❑ Going through any entry door.
- ❑ Going up and down stairs to any entry door.
- ❑ Locking or unlocking any entry door.
- ❑ Opening or closing any entry door.
- ❑ Going over the threshold at any entry door.
- ❑ Other (specify) : ____.

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ____.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ____.

____.

____.

____.

____.

____.

B. Interior Stairs

a) Location of interior stairs

Step 1. Assign a number (e.g. Stair 1, stair 2, etc.) to each flight of interior stairs that needs to be changed soon or now
Step 2. Put an (x) in the circle to next to the location of each stair in the lists below.
Step 3. Indicate the location of the interior stair(s).

❑ **STAIR 1**
- o Basement to 1st Floor
- o 1st to 2nd Floor
- o 2nd to 3rd Floor

Location : ____.

❑ **STAIR 2**
- o Basement to 1st Floor
- o 1st to 2nd Floor
- o 2nd to 3rd Floor

Location : ____.

❑ **STAIR 3**
- o Basement to 1st Floor
- o 1st to 2nd Floor
- o 2nd to 3rd Floor

Location : ____.

❑ **STAIR 4**
- o Basement to 1st Floor
- o 1st to 2nd Floor
- o 2nd to 3rd Floor

Location : ____.

b) Problems

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Using any handrail(s).
- ❑ Walking up or down any flights of stairs.
- ❑ Access to top or bottom landing.
- ❑ Other (specify) : ______________________________.

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ______________________________.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

C. Moving Around the House

a) Location of Doors, Doorways, and Halls

Step 1. list the specific doors and doorways that need to be changed soon or now and **indicate the floor** on which they are located.

Doors & Doorways	
Name	Floor

Step 2. list the specific hallways that need to be changed soon or now and **indicate the floor** on which they are located

Hallways	
Name	Floor

b) Problems

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting close enough to any door to open it.
- ❑ Opening or closing any interior door.
- ❑ Going through any interior doorway.
- ❑ Turning into any room from any hallway.
- ❑ Turning into any hallway from any room.
- ❑ Going down any hallway.
- ❑ Moving across any type of flooring material.
- ❑ Other (specify):

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ____.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ____.

____.

____.

____.

____.

____.

____.

D. Using the Bathroom

a) Location of bathrooms

Step 1. Check the box for the **bathrooms/powder room** (half bath) that need to be changed soon or now.
Step 2. Put an (x)in the circle indicate the **location** of the bathroom.

❑ **BATHROOM 1**
- Basement
- 1st Floor
- 2nd Floor
- 3rd Floor

Location : ______________________________.

❑ **BATHROOM 2**
- Basement
- 1st Floor
- 2nd Floor
- 3rd Floor

Location : ______________________________.

❑ **BATHROOM 3**
- Basement
- 1st Floor
- 2nd Floor
- 3rd Floor

Location : ______________________________.

❑ **POWDER ROOM**
- Basement
- 1st Floor
- 2nd Floor
- 3rd Floor

Location : ______________________________.

b) Problems – Toileting

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting close enough to any toilet.
- ❑ Getting on and off any toilet.
- ❑ Reaching or using toilet paper.
- ❑ Flushing any toilet.
- ❑ Other (specify):

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ______________________________.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

______________________________.

c) Problems – Bathing / Showing

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting close enough to any bathtub/shower.
- ❑ Getting in and out of any bathtub/shower.
- ❑ Sitting down in the bottom of any bathtub.
- ❑ Getting up from the bottom of any bathtub.
- ❑ Standing while showering in any shower.
- ❑ Reaching the faucet in any bathtub/ shower.
- ❑ Turning the faucet on/off in any bathtub/shower.
- ❑ Other (specify):

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ____.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ____.

____.

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____.

d) Problems / Glooming, etc.

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting close enough to any bathroom sink.
- ❑ Reaching the faucet in any bathroom sink.
- ❑ Turning the faucet on/off in any bathroom sink.
- ❑ Getting items from any cabinet or shelf.
- ❑ Other (specify):

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ____.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ____.

____.

____.

____.

____.

____.

____.

E. Using the Bedroom

a) Location of bedrooms

Step 1. Check the box for the **bedroom** that need to be changed soon or now.

Step 2. Put an (x)in the circle indicate the **location** of the bedroom.

❑ **BEDROOM 1 (MASTER)**

- o Basement
- o 1st Floor
- o 2nd Floor
- o 3rd Floor

Location : ____.

❑ **BATHROOM 2**

- o Basement
- o 1st Floor
- o 2nd Floor
- o 3rd Floor

Location : ____.

❑ **BATHROOM 3**

- o Basement
- o 1st Floor
- o 2nd Floor
- o 3rd Floor

Location : ____.

b) Problems

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting to the bed.
- ❑ Getting in and out of bed.
- ❑ Getting in and out of any chair.
- ❑ Getting to closet in the bedroom.
- ❑ Reaching items in the closet.
- ❑ Other (specify):

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ____.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ____.

____.

____.

____.

____.

____.

____.

F. Using the Kitchen

a) Identifying Kitchen Problem Areas

Step 1. Put an (x) in the circle beside the **fixture, appliance or cabinet** that needs to be changed soon or now.

FIXTURE

- o Sink
- o Other

  ____.

APPLIANCE

- o Refrigerator
- o Stove
- o Oven
- o Microwave
- o Dishwater
- o Other

  ____.

CABINET

- o Upper
  Which Ones?

  ____.
- o Lower
  Which Ones?

  ____.
- o Drawers
  Which Ones?

  ____.
- o Pantry
- o Other

  ____.

b) Problems

Step 1. Check the box labeled **problem**, if the task *is* a problem for the client to do alone or if the task cannot be done.

- ❑ Getting close enough to any of the cabinets.
- ❑ Taking items out of wall cabinets or off shelves.
- ❑ Taking items out of lower cabinets.
- ❑ Opening drawers.
- ❑ Using counter and/or workspaces.
- ❑ Reaching the kitchen faucet controls.
- ❑ Getting close enough to the kitchen sink.
- ❑ Turning kitchen faucet controls on and off.
- ❑ Using any appliance in the kitchen.
- ❑ Getting close enough to any appliance.
- ❑ Opening any appliance.
- ❑ Putting items in any appliance.
- ❑ Taking items out of any appliance.
- ❑ Other (specify):

Step 2. List the type of mobility aid(s) and assistive **devices** used in completing the task.

Device : ____.

Step 3. Provide any **comments** that will further describe the client's problem(s).

Comments : ____.

____.

____.

____.

G. Doing Other Activities

Step 1. List/describe other areas of your home that need to be changed soon or now.

____.

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3. Recommendation

A. Client's Ideas and Concerns

a) Problem Areas to be Changed

In the problem areas you want to change soon or now, **do you have any ideas about what changes you would make?**

A. In and Out	
B. Interior Stairs	
C. Around the House	
D. Bathroom	
E. Bedroom	
F. Kitchen	
G. Other Activities	

b) Areas Not Changed

In the problem areas you want to change soon or now, **is there anything that should be left alone and not changed?**

A. In and Out	
B. Interior Sta irs	
C. Around th e House	
D. Bathroom	
E. Bedroom	
F. Kitchen	
G. Other Acti vities	

B. Health Care Professional's Recommendations

a) In your professional opinion, what home modifications would you recommend and why?

____.

____.

____.

____.

____.

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____.

b) Is there any additional information needed in order to match the person with the solutions?

____.

____.

____.

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____.

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____.

APPENDIX C

Simple Survey Forms for Three Imaginary subjects

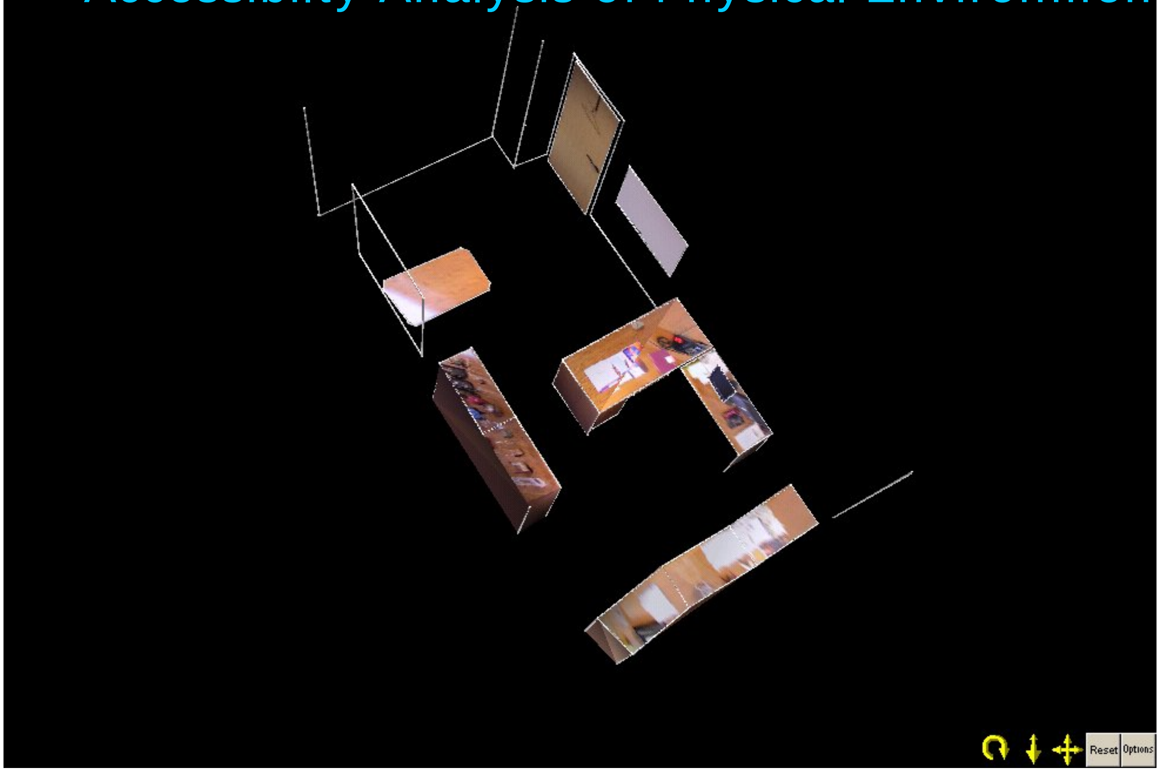
Simple Survey Form

for

Alfred

of

Virtual Reality Telerehabilitation System for Accessibilty Analysis of Physical Environment



Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Science
University of Pittsburgh

1. Personal Information

Name : Alfred

Age : 35 (years)

Height : 6′ 2″

Weight : 180 lb

Gender : Male .

2. Medical Information

Primary medical diagnosis : Multiple Sclerosis

Year of onset : 2000.

Other health conditions:

Alfred's multiple sclerosis has affected his vision and fine motor control. He was diagnosed with MS 5 years ago when he first noticed symptoms of a slight tremor and blurred vision. Except for an exacerbation 1 year ago when his significant visual loss occurred and a gradual increase in the intensity of his tremor, his symptoms have not progressed. His disease is supposed to be progressing slowly and he experienced a fall recently while walking.

3. Mobility Aids Information

❑ Scooter ❑ Manual Wheelchair ❑ Power Wheelchair

Scooter	Manual Wheelchair	Power Wheelchair
Widest Width : 19″	Widest Width :	Widest Width : .
Max. Length : 37″	Max. Length :	Max. Length : .
Seat Height : 20″	Seat Height :	Seat Height : .

Comments :

He can walk a few steps with walker. He works as a graphic designer in a company.

He uses his scooter as a primary mobility device both in the home and work.

4. Functional Movement Abilities

Tasks	Client's Rating			Mobility Aids Used	Comments
	Very Difficult	Difficult	No Difficult		
Turn a doorknob.			X		
Open a drawer.			X		
Turn on light a switch.			X		
Push a button.			X		
Sit upright in a chair.			X		
Transfer from a chair to wheelchair.			X		
Get up from chair and stand.			X	N/A	
Walk five feet.		X		WALKER	
Walk across a room.	X			N/A	
Step up on a curb.			X	WALKER	
Walk up three steps.	X			N/A	
Walk up 10 steps or more.	X			N/A	
Roll/propel wheelchair 5ft.			X	SCOOTER	
Roll/propel wheelchair across a room			X	SCOOTER	

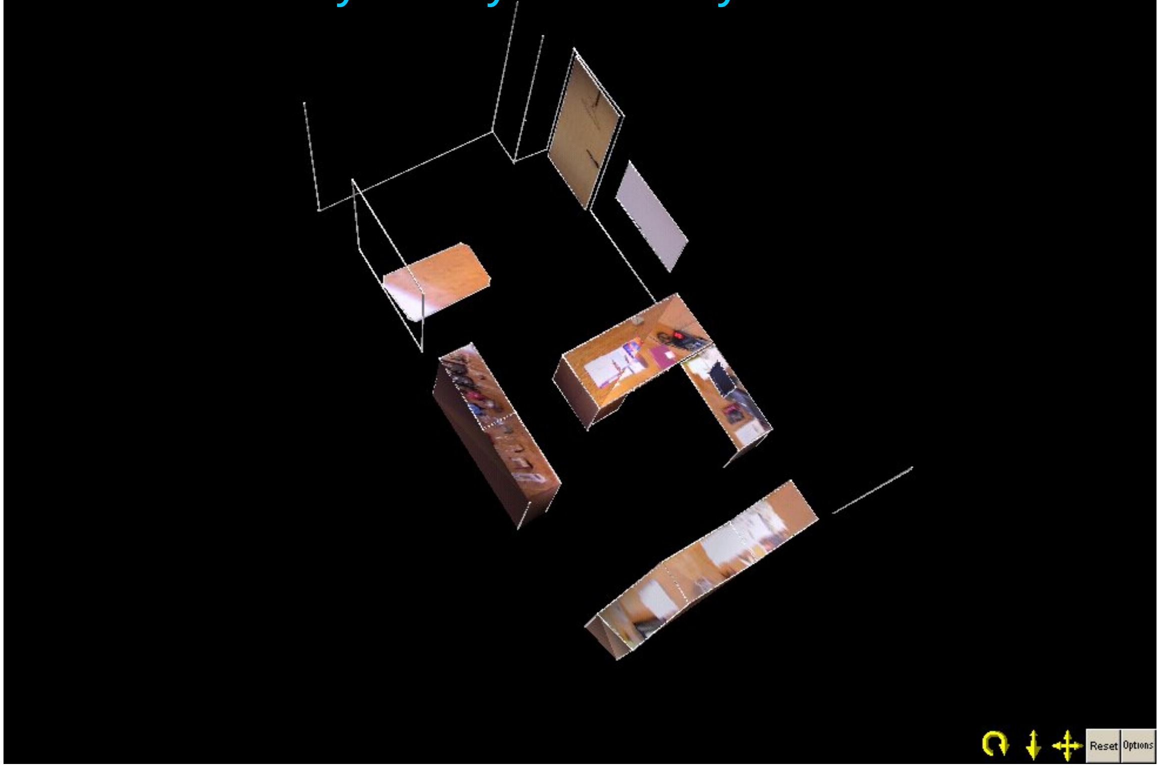
Simple Survey Form

for

Bill

of

Virtual Reality Telerehabilitation System for Accessibilty Analysis of Physical Environment



Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Science
University of Pittsburgh

1. Personal Information

Name : Bill

Age : 16 (years)

Height : 5’ 5”

Weight : 115 lb

Gender : Male .

2. Medical Information

Primary medical diagnosis : spastic quadriplegia cerebral palsy

Year of onset : 1988.

Other health conditions:

Bill is a 16 year old boy with a diagnosis of spastic quadriplegia cerebral palsy. He has recently undergone surgery to correct jaw and palate alignment. He has had several lower extremity orthopedic surgeries. The most recent was a tibialis anterior tendon transfer that failed to correct his foot position. Bill has been in a power wheelchair since he was a small child. He also walks for short distances and has a manual wheelchair for back up when he is unable to take his power wheelchair.

3. Mobility Aids Information

❑ Scooter | ❑ Manual Wheelchair | ❑ Power Wheelchair

❑ Scooter	❑ Manual Wheelchair	❑ Power Wheelchair
Widest Width : ___________	Widest Width : 22″	Widest Width : 27″ .
Max. Length : ___________	Max. Length : 35″	Max. Length : 44″ .
Seat Height : ___________	Seat Height : 25″	Seat Height : 27.5″ .

Comments :

Bill is currently using an Permobile Entra power wheelchair as a primary mobility device, which he has had for almost 5 years. He has a Quickie 2 manual wheelchair as a back up. He is using a posture control (posterior) Kaye walker as an anterior walker, but has difficulty maneuvering it as it is designed to roll behind him.

4. Functional Movement Abilities

Tasks	Client's Rating			Mobility Aids Used	Comments
	Very Difficult	Difficult	No Difficult		
Turn a doorknob.		X			
Open a drawer.	X				
Turn on light a switch.		X			
Push a button.		X			
Sit upright in a chair.	X				
Transfer from a chair to wheelchair.			X		
Get up from chair and stand.		X		WALKER	
Walk five feet.		X		WALKER	
Walk across a room.		X		WALKER	
Step up on a curb.		X		N/A	
Walk up three steps.	X			N/A	
Walk up 10 steps or more.	X			N/A	
Roll/propel wheelchair 5ft.			X	Power Wheelchair	
Roll/propel wheelchair across a room			X	Power Wheelchair	

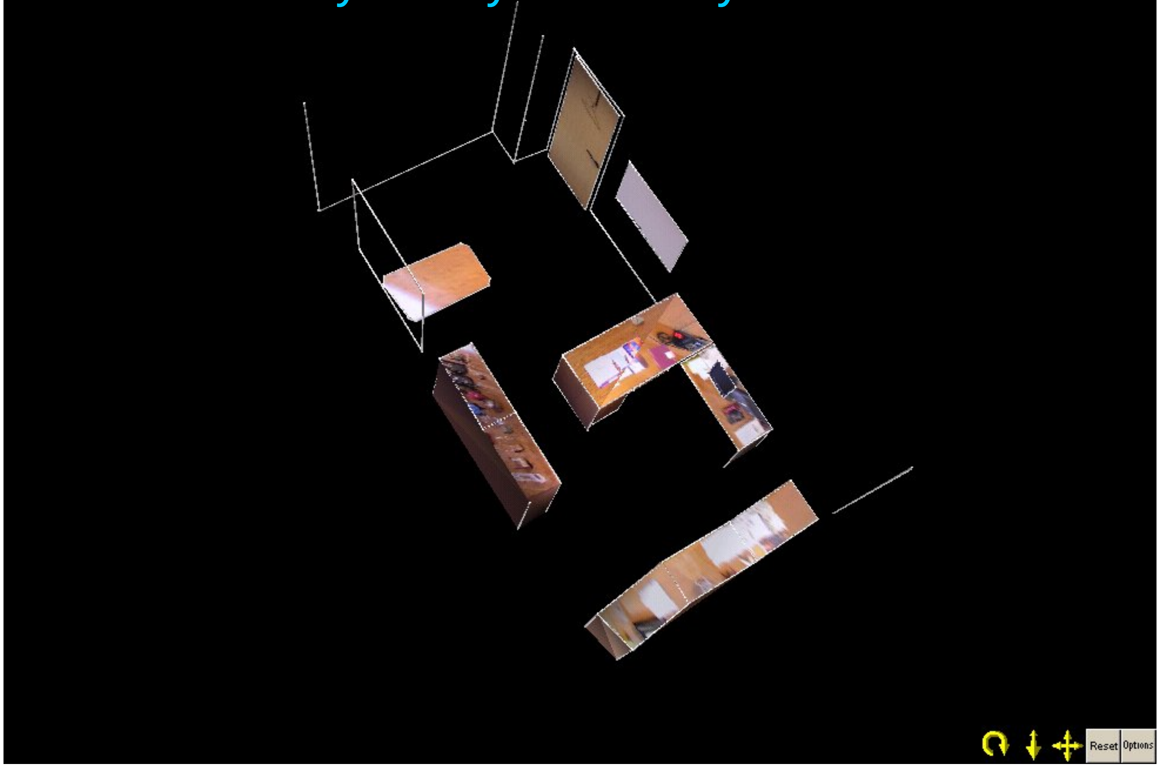
Simple Survey Form

for

Sally

of

Virtual Reality Telerehabilitation System for Accessibilty Analysis of Physical Environment



Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Science
University of Pittsburgh

1. Personal Information

Name : Sally

Age : 31 (years)

Height : 5′ 5″

Weight : 120 lb

Gender : Female .

2. Medical Information

Primary medical diagnosis : Spinal Cord Injury at T-11, ASIA grade A(complete)

Year of onset : 2005.

Other health conditions:

On April 16, 2005, 31-year-old Shally – mother of two children– sustained multiple fractures and a spinal cord injury from a car accident. She was rushed into a local hospital of University of Pittsburgh Medical System where she was diagnosed with a right femur fracture, rib fracture, T11 burst fracture and complete paraplegia. She was very depressed and lacked confidence in her abilities to lead a normal life. However, she wants to return home to care of her children.

3. Mobility Aids Information

❑ Scooter

Widest Width : ____________

Max. Length : ____________

Seat Height : ____________

❑ Manual Wheelchair

Widest Width : 21″

Max. Length : 32″

Knee Height : 25”

❑ Power Wheelchair

Widest Width : ____________.

Max. Length : ____________.

Seat Height : ____________.

Comments :

Her medical conditions result in her being dependent on the use of an ultralightweight manual wheelchair for all mobility needs both in the home and community.

4. Functional Movement Abilities

Tasks	Client's Rating			Mobility Aids Us ed	Comments
	Very Difficult	Difficult	No Difficult		
Turn a doorknob.			X		
Open a drawer.			X		
Turn on light a s witch.			X		
Push a button.			X		
Sit upright in a ch air.			X		
Transfer from a c hair to wheelchair .			X		BY HERSELF
Get up from chair and stand.	X			N/A	
Walk five feet.	X			N/A	
Walk across a ro om.	X			N/A	
Step up on a cur b.		X		WHEELCHAIR	
Walk up three ste ps.	X			N/A	
Walk up 10 steps or more.	X			N/A	
Roll/propel wheel chair 5ft.			X		
Roll/propel wheel chair across a ro om			X		

APPENDIX D

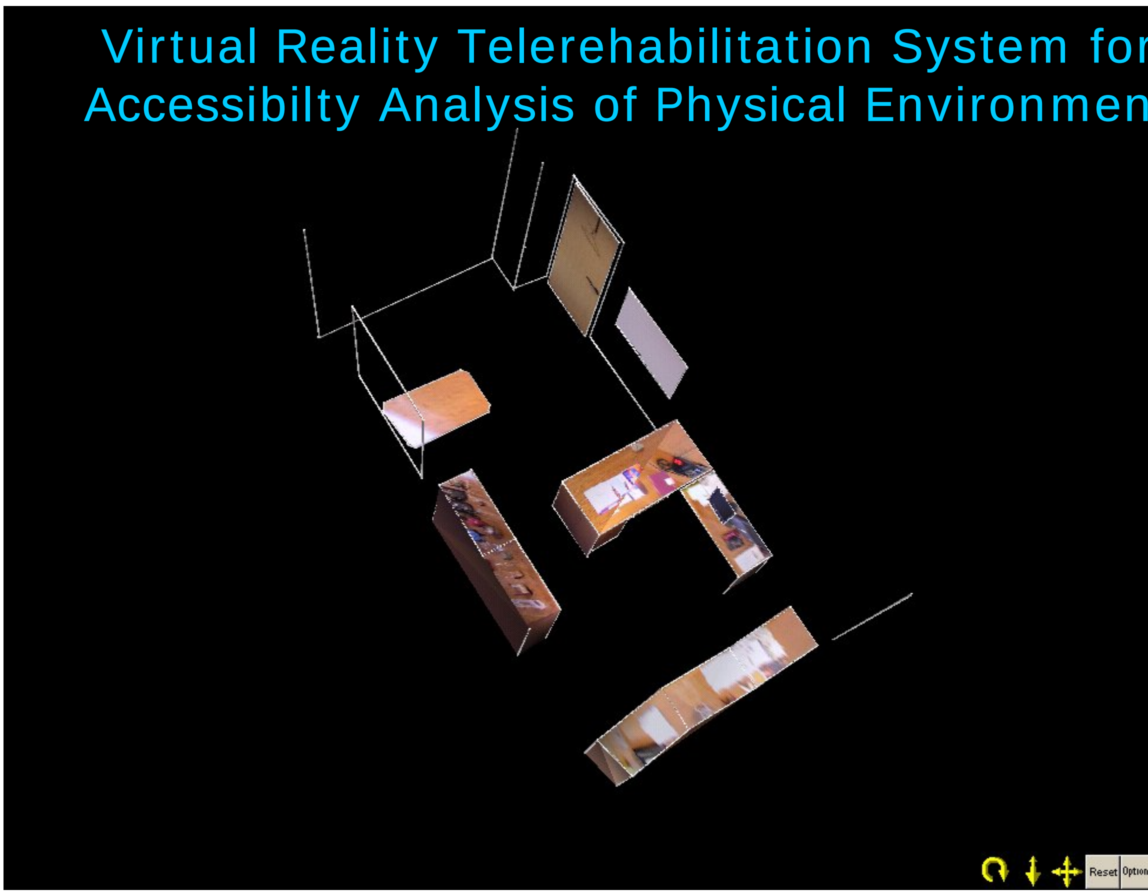
Evaluation Form

E V A L U A T I O N   F O R M

for

Accessibility Assessment

of



Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Science
University of Pittsburgh

Name of Project : Sheet# : A-( )

Assessment method : VRTS / Conventional

B. Entrances to the home # : A– ( )

check		Location	Type
A01	check	Having enough space to build a ramp.	
		Specify the modification	
A02	check	Having enough space to install a stair glide.	
		Specify the modification	
A03	check	Having enough space to install a lift or elevator.	
		Specify the modification	
A04	check	Reaching the entrance from the street, driveway or sidewalk.	
		Specify the modification	
A05	Check	Maneuvering at the entry door.	
		Specify the modification	
A06	Check	Going through the entry door.	
		Specify the modification	
A07	Check	Going up and down stairs.	
		Specify the modification	
A08	Check	Locking or unlocking the entry door.	
		Specify the modification	
A09	Check	Opening or closing the entry door.	
		Specify the modification	
A10	Check	Going over the threshold at the entry door.	
		Specify the modification	
A11	check	Other (specify) :	
		Specify the modification	

/ /05

Signature of evaluator Date

/ /05

Signature of investigater Date

Name of Project : Sheet# : B-( )

Assessment method : VRTS / Conventional

C. Interior Stairs		# : B- ( )
check	Location	Type

B01	check	Having enough space to build a ramp.
		Specify the modification
B02	check	Having enough space to install a stair glide.
		Specify the modification
B03	check	Having enough space to install a lift or elevator.
		Specify the modification
B04	check	Using any handrail(s).
		Specify the modification
B05	Check	Walking up or down any flights of stairs.
		Specify the modification
B06	Check	Access to top or bottom landing.
		Specify the modification
B07	check	Other (specify) :
		Specify the modification

/ /05

Signature of evaluator Date

/ /05

Signature of investigater Date

Name of Project : Sheet# : C-( )

Assessment method : VRTS / Conventional

D. Moving Around the House		# : C– ( )	
check		Location of Door, Doorway, and Hallway	Floor
C01	check	Maneuvering at a door to open it.	
		Specify the modification	
C02	Check	Opening or closing an interior door.	
		Specify the modification	
C03	Check	Going through an interior doorway.	
		Specify the modification	
C04	Check	Turning into a room from a hallway.	
		Specify the modification	
C05	Check	Turning into a hallway from a room.	
		Specify the modification	
C06	Check	Going down a hallway.	
		Specify the modification	
C07	Check	Moving across a flooring material.	
		Specify the modification	
C08	check	Other (specify) :	
		Specify the modification	

/ /05

Signature of evaluator Date

/ /05

Signature of investigater Date

Name of Project : Sheet# : D-(   )

Assessment method : VRTS / Conventional

E. Using the Bathroom # : D– (   )

check	Location	Floor

D01	check	Having enough space to use a hoist lift.
		Specify the modification
D02	check	Having enough space to install a ceiling mounted hoist.
		Specify the modification
D03	check	Maneuvering space at a toilet.
		Specify the modification
D04	Check	Getting on and off a toilet.
		Specify the modification
D05	Check	Reaching or using toilet paper.
		Specify the modification
D06	Check	Flushing a toilet.
		Specify the modification
D07	Check	Turning into a hallway from a room.
		Specify the modification
D08	Check	Going down a hallway.
		Specify the modification
D09	Check	Maneuvering space at a bathtub/shower.
		Specify the modification
D10	Check	Getting in and out of a bathtub/shower.
		Specify the modification
D11	Check	Sitting down in the bottom of a bathtub.
		Specify the modification
D12	Check	Getting up from the bottom of a bathtub.
		Specify the modification
D13	Check	Standing while showering in a shower.
		Specify the modification

D14	Check	Reaching the faucet in a bathtub/ shower. Specify the modification
D15	Check	Turning the faucet on/off in a bathtub/shower. Specify the modification
D16	Check	Maneuvering space at a bathroom sink. Specify the modification
D17	Check	Reaching the faucet in a bathroom sink. Specify the modification
D18	Check	Turning the faucet on/off in a bathroom sink. Specify the modification
D19	Check	Getting items from a cabinet or shelf. Specify the modification
D20	check	Other (specify) : Specify the modification

/ /05

Signature of evaluator Date

/ /05

Signature of investigater Date

Name of Project : Sheet# : E-(   )

Assessment method : VRTS / Conventional

F. Using the Bedroom			# : E- ( )
check		Location ○ Bedroom1(Master) ○ Bedroom2__________________. ○ Bedroom3__________________. ○ Bedroom4__________________.	Type ○ Basement ○ 1st ○ 2nd ○ 3rd
E01	check	Having enough space to use a hoist lift. Specify the modification	
E02	check	Getting to the bed. Specify the modification	
E03	Check	Getting in and out of bed. Specify the modification	
E04	Check	Getting to closet in the bedroom. Specify the modification	
E06	Check	Reaching items in the closet. Specify the modification	
E07	check	Other (specify) : Specify the modification	

/   /05

Signature of evaluator Date

/   /05

Signature of investigater Date

Name of Project : Sheet# : F-( )

Assessment method : VRTS / Conventional

G. Using the Kitchen # : F– ( )

check		Problem Area	◯ Sink ◯ Other Fixture______________________. ◯ Refrigerator ◯ Stove ◯ Oven ◯ Microwave ◯ Dishwasher ◯ Other Appliance______________________. ◯ Upper Cabinet______________________. ◯ Lower Cabinet______________________. ◯ Drawer Cabinet______________________. ◯ Pantry Cabinet ◯ Other Cabinet______________________.
F01	check	Maneuvering space at one of the cabinets. Specify the modification	
F02	Check	Taking items out of wall cabinets or off shelves. Specify the modification	
F03	Check	Taking items out of lower cabinets. Specify the modification	
F04	Check	Opening drawers. Specify the modification	
F05	Check	Using counter and/or workspaces. Specify the modification	
F06	Check	Reaching the kitchen faucet controls. Specify the modification	
F07	Check	Maneuvering space at the kitchen sink. Specify the modification	
F08	Check	Turning kitchen faucet controls on and off. Specify the modification	
F09	Check	Using any appliance in the kitchen.	

		Specify the modification
F10	Check	Maneuvering space at an appliance.
		Specify the modification
F11	Check	Opening or Operating an appliance.
		Specify the modification
F12	Check	Putting items in an appliance.
		Specify the modification
F13	Check	Taking items out of an appliance.
		Specify the modification
F14	check	Other (specify) :
		Specify the modification

/ /05

Signature of evaluator Date

/ /05

Signature of investigater Date

_Name of Project :   Sheet# : G-(   )

Assessment method : VRTS / Conventional

H. Doing Other Activities		# : G- ( )
check		Other Area
G01	check	Answering the door bell
		Specify the modification
G02	check	Answering the telephone
		Specify the modification
G03	check	Calling for help
		Specify the modification
G04	check	Describe a task
		Specify the modification
G05	check	Describe a task
		Specify the modification
G06	check	Describe a task
		Specify the modification
G07	check	Describe a task
		Specify the modification

/   /05

Signature of evaluator   Date

/   /05

Signature of investigater   Date

Name of Project :   Sheet# : T

Assessment method : VRTS

Total number of differences

/ /05

Signature of investigater   Date

APPENDIX E

Formal Consent Form

University of Pittsburgh

School of Health and Rehabilitation Sciences
Department of Rehabilitation Science and Technology

Forbes Tower, Suite 5044
Pittsburgh, PA 15260
412-383-6596
Fax: 412-383-6597
TDD: 412-383-6598

CONSENT TO ACT AS A SUBJECT IN A RESEARCH STUDY

TITLE: *A Virtualized Reality TeleRehabilitation System for Accessibility Analysis of Physical Environment*

PRINCIPAL INVESTIGATOR: David M. Brienza, Ph.D. Associate Professor
5044 Forbes Tower Pittsburgh, PA 15260 Phone: 412) 383-6591

CO-INVESTIGATORS: Jongbae Kim, Graduate Student Researcher
5044 Forbes Tower Pittsburgh, PA 15260 Phone: 412) 383-6581

SOURCE OF SUPPORT: Department of Veteran's Affair

Why is this study being done?
The purpose of this research study is to test a new system of assessing the wheelchair accessibility of your home. Accessibility means how well you can move around in your home, including entering and exiting your home, going through doors, using sink or shower, and so forth. The system we are testing is called the Virtual Reality Telerehabilitation System (VRTS). This system will use a computer to study photographs of your home and create an imaginary version of your home on the computer. We will assess the value of our newly developed method by examining agreement of assessment results obtained using the VRTS and the conventional in person (CIP) methods.

Why is this study being done?
The purpose of this research study is to test a new system of assessing the wheelchair accessibility of your home. Accessibility means how well you can move around in your home, including entering and exiting your home, going through doors, using sink or shower, and so forth. The system we are testing is called the Virtual Reality Telerehabilitation System (VRTS). This system will use a computer to study photographs of your home and create an imaginary version of your home on the computer. We will assess the value of our newly developed method by examining agreement of assessment results obtained using the VRTS and the conventional in person (CIP) methods.

Who is being asked to take part in this study?
Six individuals who own or occupy a home that is being evaluated for a home modification will be invited to participate in this research study. Participants in this study will be male and female,

older than 18 years of age, and have asked the home modification to the architect firm, Lynch & Associates.

What are the procedures of this study?

If you agree to participate in this research study, you will be asked to complete a survey about your home and mobility device and have pictures taken of your home physical environment. A survey form and a camera set that includes a digital camera, a ruler, a written instruction and guidelines for taking good pictures will be shipped to your home. You can take pictures with the assistance of family members, neighbors, a regional social worker, or a volunteer. But if you cannot do that, you will be asked to allow a research assistant, who is a part time employed student, to take the pictures. After the survey is filled out and photos are taken, the architect will visit your home to conduct normally his/her conventional in person assessment. An investigator in this study will analyze the photos of and create 3-dimensional models of your home. An investigator in this study will analyze the pictures and create 3-dimensional models of your home. Once the 3D models have been constructed, they will be given to the rehabilitation engineer with the returned survey form and 2D photos.

What are the possible risks and discomforts of this study?

There are no risks and limitations placed on you due to participating in this research study because this study investigates only the physical environment of your home not yourself. You may be inconvenienced during the acquisition of images procedure due to someone visiting your home and taking pictures of your home physical environment.

Will I benefit from taking part in this study?

You will not directly benefit from participating in this study. Your participation may help researchers to determine a better intervention method for assessing the accessibility of the wheelchair user's home.

Are there any costs to me if I participate in this study?

There will be no cost to you for your participation in this study. And you will still be responsible for any fees associated with services you receive from Lynch & Associates just as if you are not involved in this study.

How much will I be paid if I complete this study?

You will be paid a total of $50 if you complete all parts of this study. If, for whatever reason, you complete part but not all of the study, the terms of this payment will be as follows: 1) $20 for completing the survey about your home and mobility device; 2) an additional $20 for completing the photographing of your home environment; 3) an additional $10 for completing the conventional in person assessment by the architect.

Will anyone know that I am taking part in this study?

All records pertaining to your involvement in this study are kept strictly confidential (private) and any data that includes your identity will be stored in locked files at all times. A number will be assigned to your information and your name will be separated from this coded information during storage. At the end of this study, any records that personally identify you will remain stored in locked files and will be kept for a minimum of five years. Your identity will not be revealed in any description or publications of this research. In unusual cases, your research records may be released in response to an order from a court of law. It is also possible that authorized representatives from the University of Pittsburgh Research Conduct and Compliance Office, the University of Pittsburgh IRB, or the sponsors of this research study (Department of Veteran's Affair) may review your data for the purpose of monitoring the conduct of this study. Also, if the investigators learn that you or someone with whom you are involved is in serious danger or potential harm, they will need to inform the appropriate agencies, as required by Pennsylvania law.

Is my participation in this study voluntary?

Yes! Your participation in this study is completely voluntary. You may refuse to take part in it, or you may stop participating at any time, even after signing this form. Your decision will not affect your relationship with the architect firm, Lynch & Associates or the University of Pittsburgh, nor will you lose any benefits that you might be eligible for because of what you decide. You may be withdrawn from the study at any time by the investigators: for example, if you were found to meet any of the study criteria that would exclude you from participating.

****

VOLUNTARY CONSENT

All of the above has been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that such future questions will be answered by the researchers listed on the first page of this form. Any questions which I have about my rights as a research participant will be answered by the Human Subject Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668).

By signing this form, I agree to participate in this research study. A copy of this consent form will be given to me.

______________________________	____________
Participant's Signature	Date
____________________________________	_________________________
Witness's Printed Name	Relationship to Participant
__________________________________	____________
Witness's Signature	Date

CERTIFICATION of INFORMED CONSENT

I certify that I have explained the nature and purpose of this research study to the above-named individual(s), and I have discussed the potential benefits and possible risks of study participation. Any questions the individual(s) have about this study have been answered, and we will always be available to address future questions as they arise.

____________________________________	_________________________
Printed Name of Person Obtaining Consent	Role in Research Study
__________________________________	____________
Signature of Person Obtaining Consent	Date

APPENDIX F

Cover Letter

University of Pittsburgh

School of Health and Rehabilitation Sciences
Department of Rehabilitation Science and Technology

Forbes Tower, Suite 5044
Pittsburgh, PA 15260
412-383-6596
Fax: 412-383-6597
TDD: 412-383-6598

[Date]

Dear [Participant's Name],

Thank you very much for your interest in the research study entitled "A Virtualized Reality TeleRehabilitation System for Accessibility Analysis of Physical Environment." As we discussed over the telephone on [Date of initial conversation], I have enclosed a consent form for your review and signature.

Please take time to read the form carefully and note any questions you may have. **Before you sign and date the consent form, please contact me at 412-383-6581 so that I may address any questions or concerns you may have**. It is very important that you contact me **BEFORE** you sign the consent form so that I may be sure you fully understand the study and its associated risks and benefits before you agree to participate.

Once we have discussed the form and all your questions have been answered, please do the following:

1. Initial the bottom right-hand corner of each page of the form in the blank provided.
2. Sign your name on the line labeled "Participant's Signature" (page 4 of the form).
3. Fill in the date you signed the form.
4. If you agree to participate in this research study but are unable to sign your name, you should make your "mark" on the Participant Signature line. And a witness to this "mark" should make his/her signature and date it.
5. Mail the completed consent form to me using the enclosed self-addressed stamped envelope.

Once I receive your consent form, I will complete the last section and mail a copy of the completed form back to you for your records.

Please do not hesitate to contact me at 412-383-6581 or jbkim@pitt.edu if you have any questions about the study. Thank you again for your interest in this study.

Sincerely,

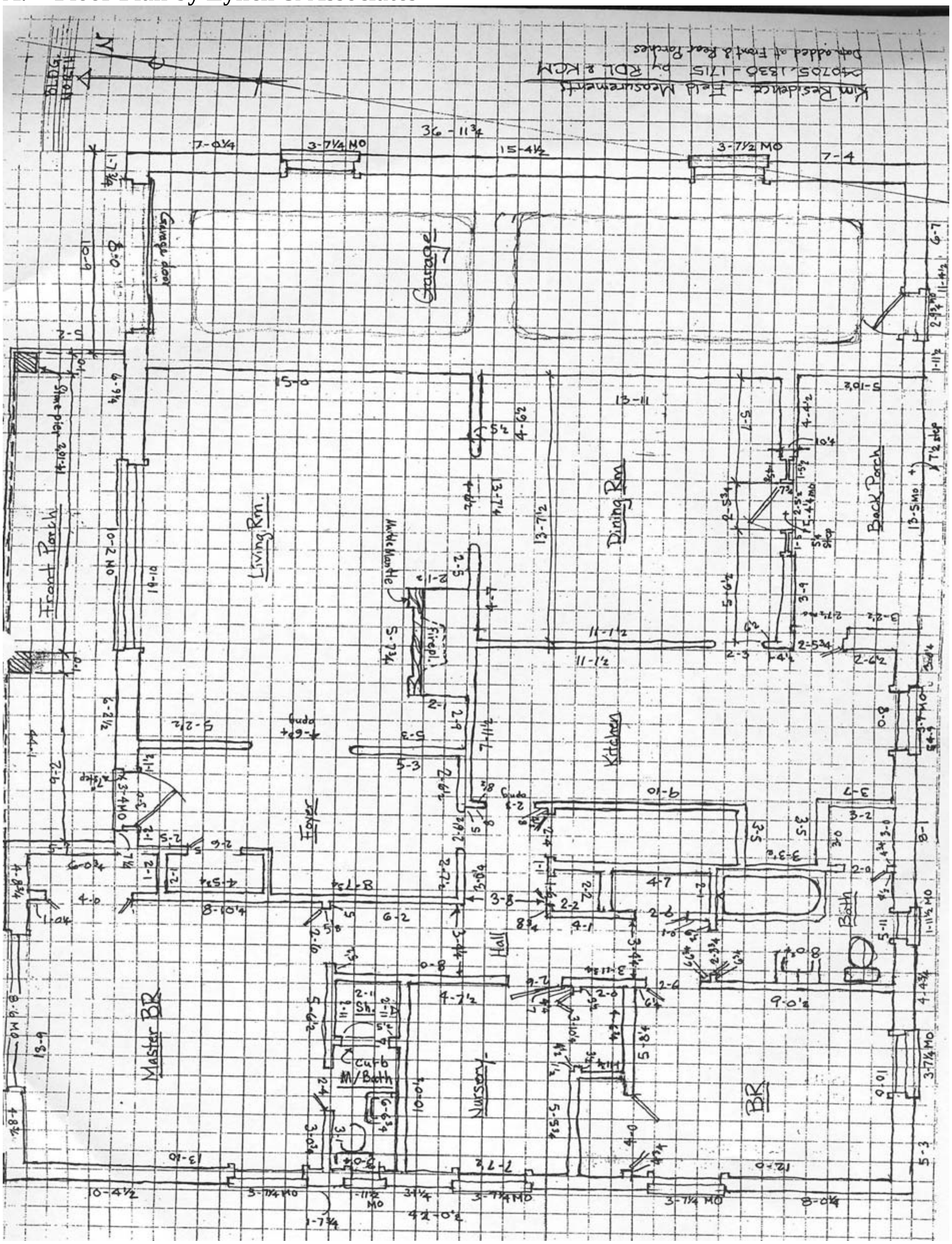
Jong-Bae Kim
Study Coordinator

APPENDIX G

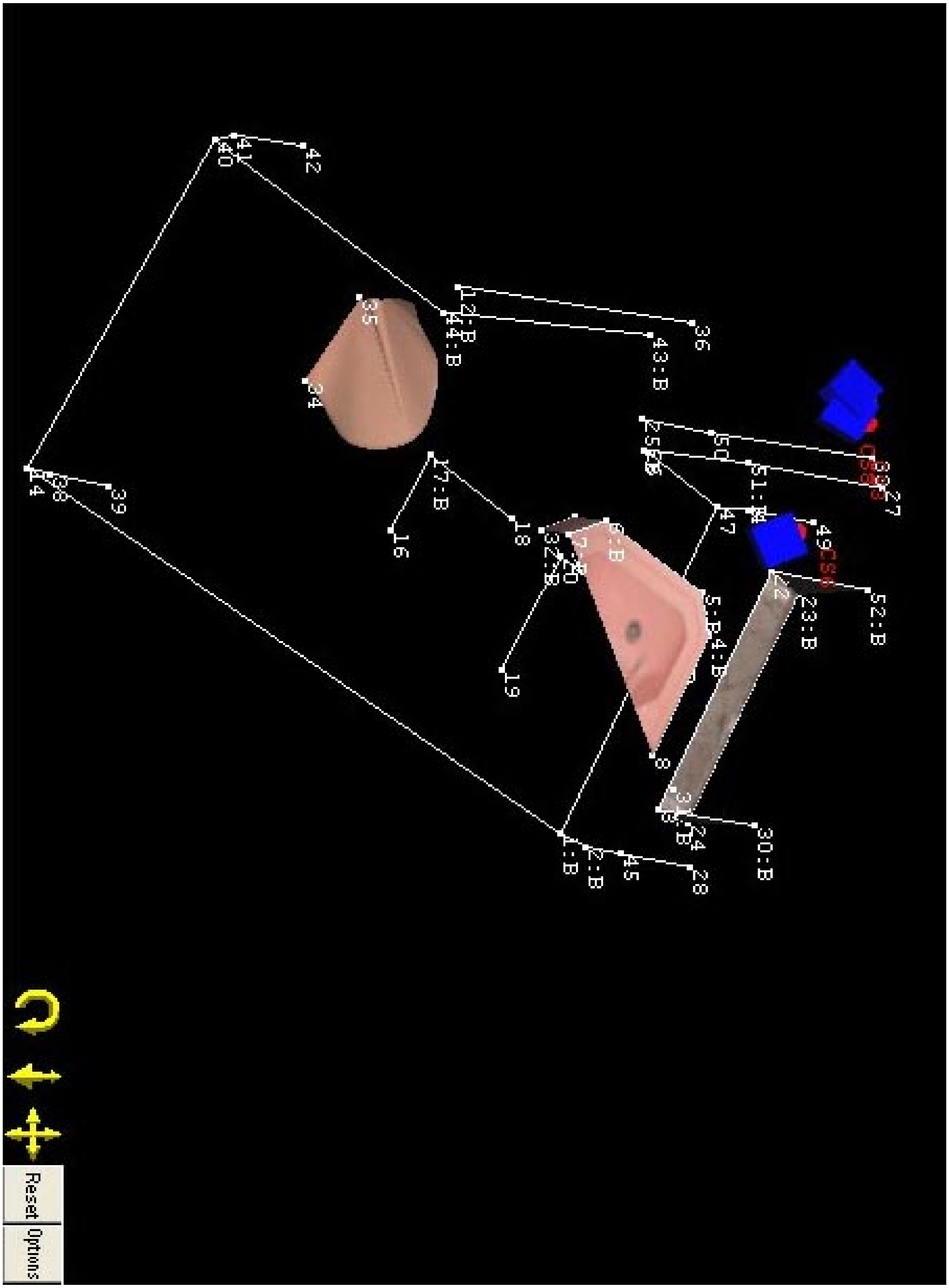
Sample Pictures, 3D Models and Floor Plans of Three Houses

1. First House

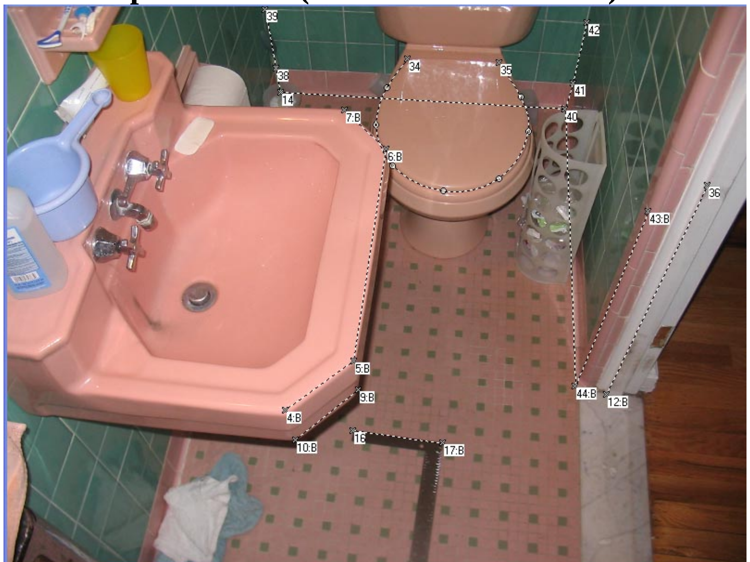
A. Floor Plan by Lynch & Associates

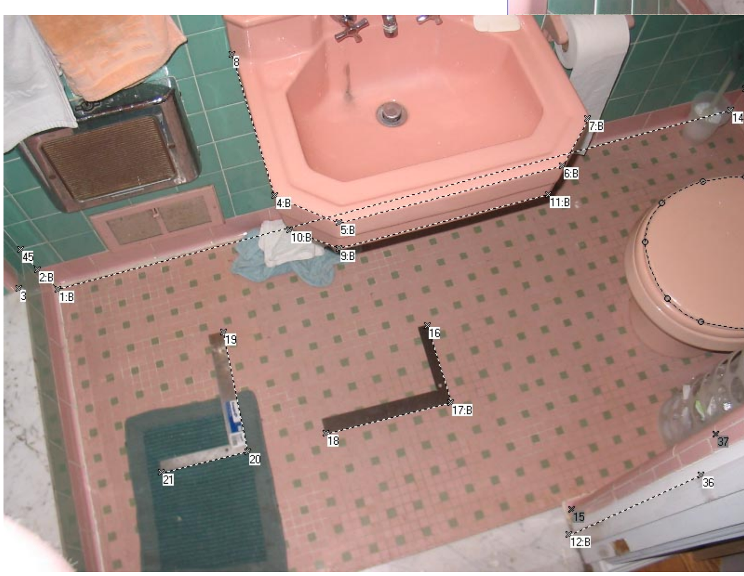


B. A Sample 3D model (Bathroom of 1st house)



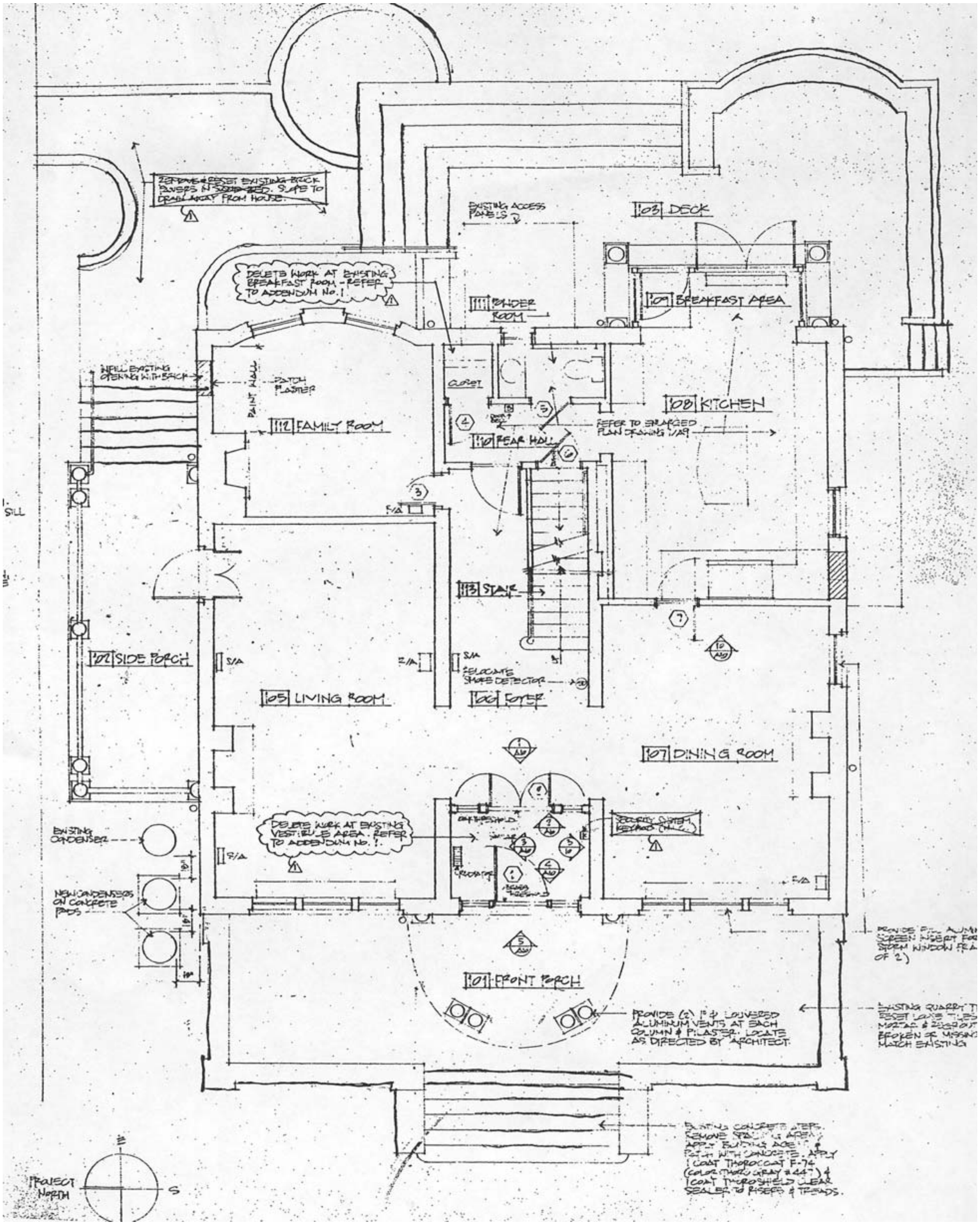
C. Sample Pictures (Bathroom of 1st house)



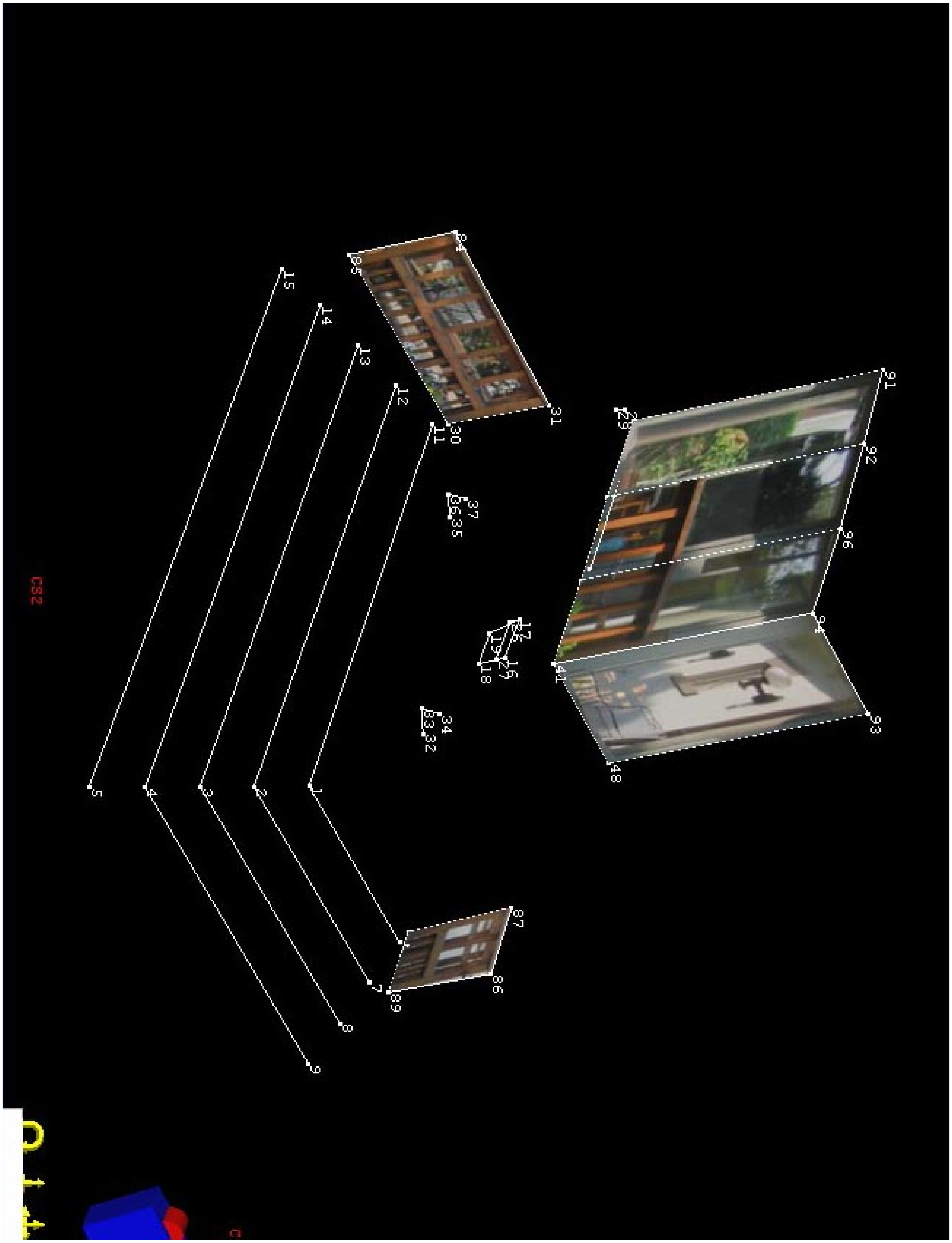


2. Second House

A. Floor Plan by Lynch & Associates



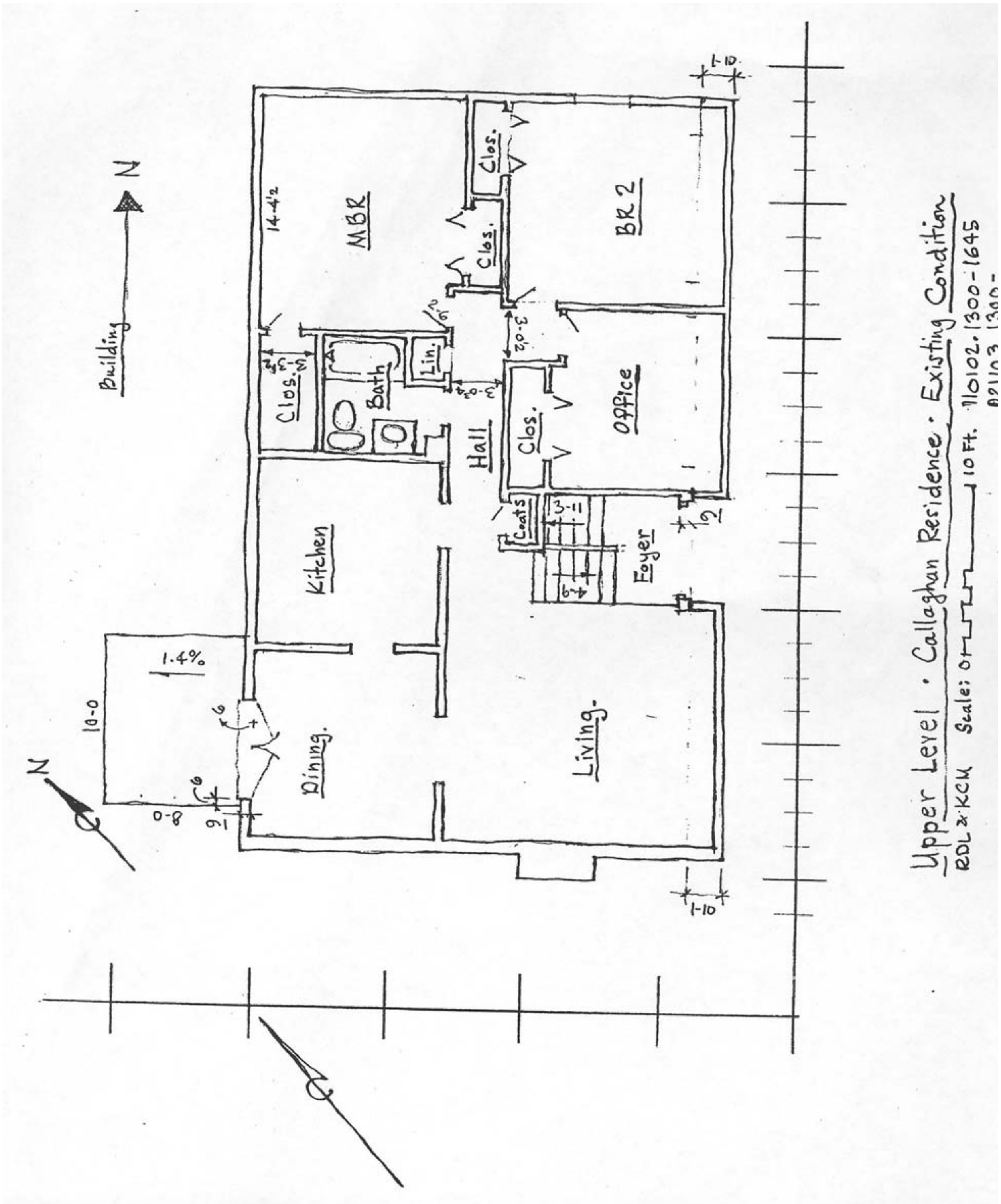
B. A Sample 3D model (Back Entrance of 2nd house)



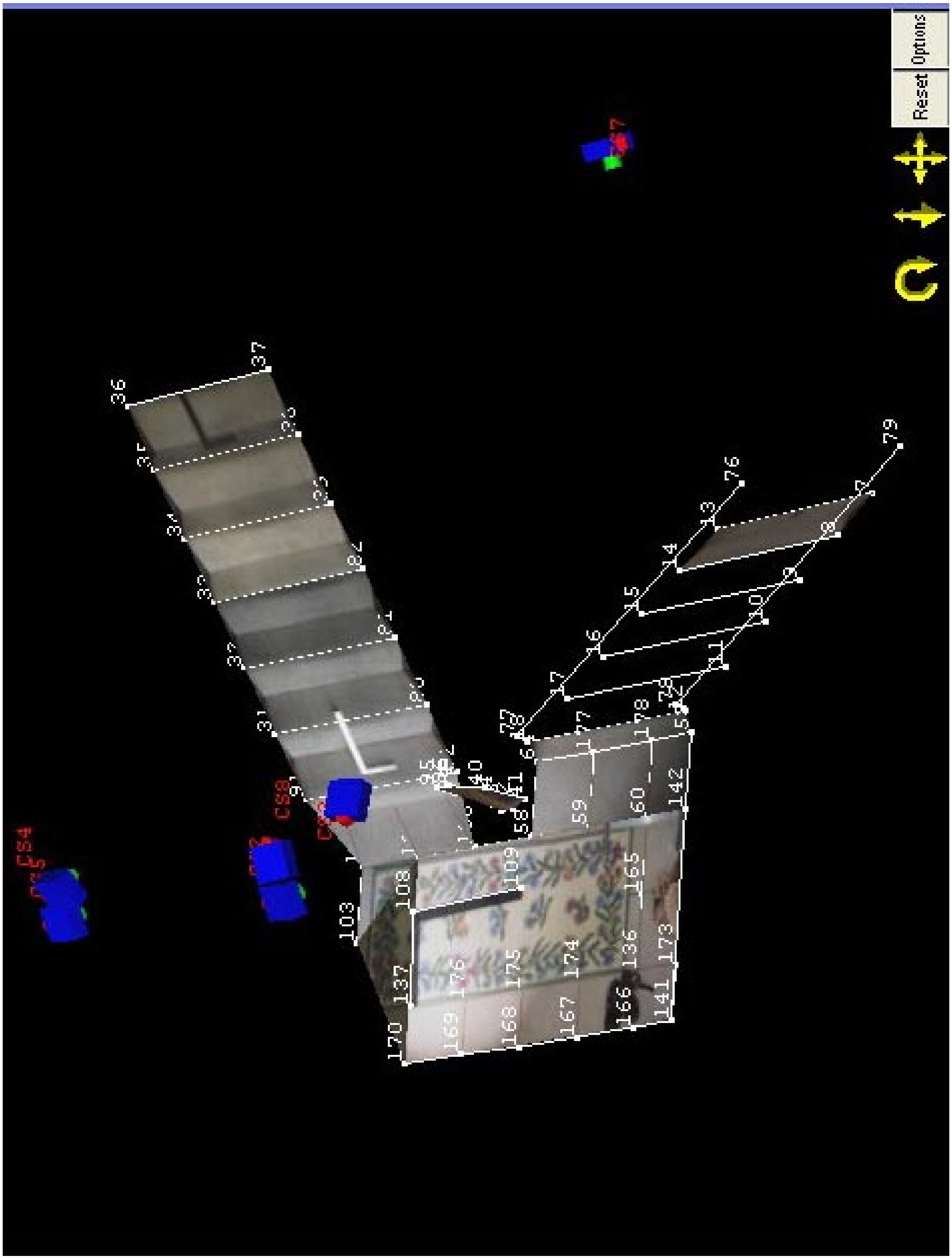
C. Sample Pictures (Back Entrance of 2nd house)

3. Third House

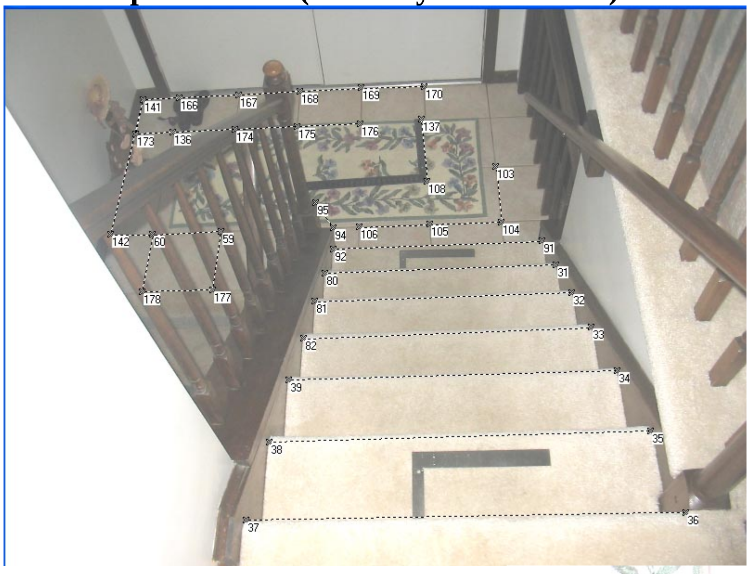
A. Floor Plan by Lynch & Associates

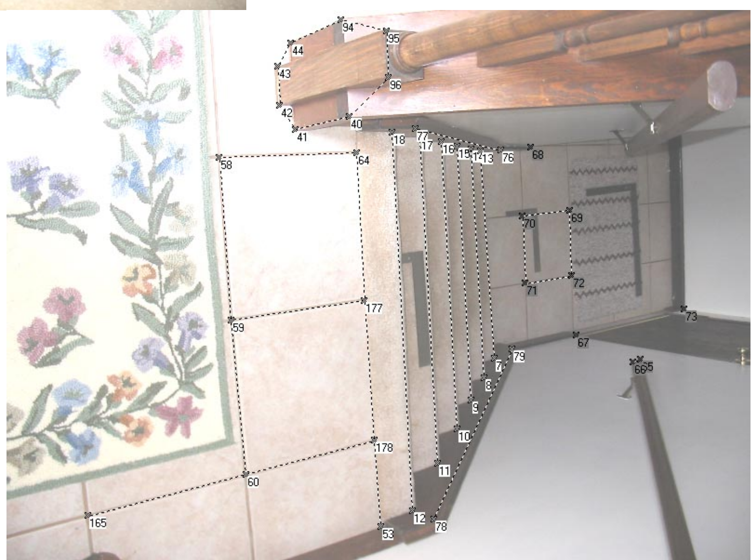


B. A Sample 3D model (Stairway of 3rd house)



C. Sample Pictures (Stairway of 3rd house)





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