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Prototype Evaluation of a User Centered Design System for Smart Homes

Mohammadali Heidari Jozam[1*], Erfaneh Allameh[1], Bauke de Vries[1] and Harry Timmermans[1]
[1] Eindhoven University of Technology,
Department of Built Environment,
P.O. Box 513
5600 MB Eindhoven
The Netherlands
m.heidari.jozam@tue.nl

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Abstract: Using system prototypes in the domain of Smart Home Design has become a principal research approach in this emerging area. Several virtual (VR) simulators propose to reduce the testing costs by replacing actual home services with virtual objects to visualize the behaviour of the Smart Home. Most developed prototypes are used in functionality tests of Smart Homes with less attention to the users' point of view. While the efforts toward developing user centered system prototypes of Smart Homes are rare, we propose a VR prototype, which not only visualises Smart Home spaces and functions but also let users perform several real time interactions. It is assumed that using this system improves users' understanding of Smart Homes and their involvement in the communication with designers. Accordingly, designers will be able to collect users' feedback of the design in virtual task-based interactions. Therefore, this system can be a helpful toolset for designers to consider users` attitude and preferences and to increase users` acceptance of Smart Homes. Considering the assumption, we outline an experiment to evaluate the efficiency of this VR prototype. In the following, we report the outcomes of this evaluation experiment.

1. INTRODUCTION

In this paper, we propose a VR prototype of a User Centered Design (UCD) system for Smart Homes, while most of the current Smart Home design tools are concentrating on technical issues. (de Vries et al., 2012) assume that applying this VR prototype in design process can improve users` understanding of Smart Homes as well as designer` understanding of users` preferences and real use. In the following, we evaluate this argument in an experiment.

The outline of this paper is as follows. First, we argue the potential of a UCD-System in Smart Home development and review existing prototypes. Then, the structure of our VR prototype is discussed: 1) Smart BIM which is an interactive virtual model for simulating the functions of smart technologies. 2) Smart Design System which let users perform real-time interactions and tasks. 3) Activity Preference plug-in which let users express their activity preferences. Next, we introduce an evaluation experiment for the efficiency test of this prototype. The evaluation is based on the findings of a questionnaire filled by participants after interacting with the prototype. Finally, we draw a conclusion on the consequences of this VR prototype for the design process and the building industry of Smart Homes.

The main objective of this paper is to know whether a UCD-System for Smart Homes can increase user contribution in the design process and improve both users` acceptance and design optimisation of Smart Homes.

2. WHY A UCD- SYSTEM FOR SMART HOMES?

As any Smart Home will be eventually used by end users, providing a method to increase users` contribution in design process for revealing their preferences is indispensable; especially for addressing several key problems in *User Acceptance of Smart Home*. As it is depicted in Figure1, there are many challenges in a way moving from *Smart Home Vision* to *Smart Home Reality*. Venkatesh studies (2008) show that in many cases consumers are unaware of the benefits of new smart technologies. He believed that by growing this awareness, the demand for Smart Homes` products will rise. Hence, the *Smart Home Design* requires collaborative efforts in integration of design process with *Users` Contribution*. While the common justification for much of the researches in the *Smart Home Design* is the technological facilitation of devices, regardless of User Feedbacks. By using such a system designers can gain users` *General Attitude*, *Lifestyle Preferences* (technology use) and even their *Spatial Preferences*. Applying a *UCD System tool* instead of technical tools will result a better home design.

Figure 1 shows the role of a UCD system tool in the design process of Smart Homes from a vision to reality.

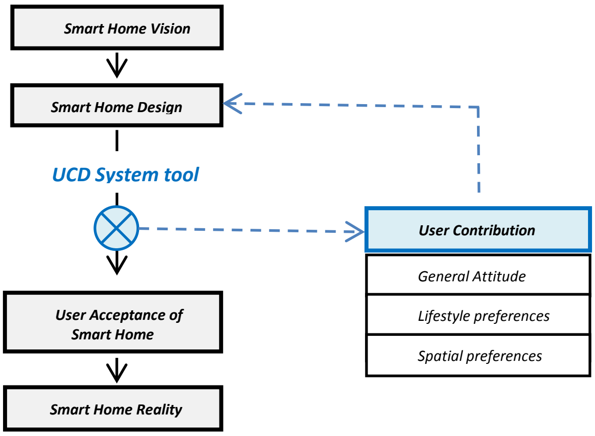


Figure 1. The role of a UCD System tool in design process of Smart Homes

Using VR prototypes in the domain of Smart Home Design is not new and System prototyping has since become a principal research approach in this emerging area. There are other examples such as:

– CASS is Context-Aware Simulation System for Smart Home. A 2D application tool which generates the context information associated with virtual sensors and virtual devices in a Smart Home domain. By using CASS, the developer can determine optimal sensors and devices in a smart home (Park et al., 2007).

– ISS is an Interactive Smart Home Simulator. A 2D application tool focuses on controlling and simulating the behavior of an intelligent house. It determines the optimal sensor network and device placement (Van Nguyen et al., 2009).

– ViSi for SM4All is a 3D environment with interactive and proactive devices. It is able to adapt the behavior of devices to the needs of the home inhabitants. For example, a movie may be automatically paused when the subject leaves the room, and then launched again when he/she is back; or the windows are automatically opened to regulate the air condition (Lazovik et al., 2009).

Figure 2. a) CASS: Context-Aware Simulation System, b) ISS: Interactive Smart Home Simulator, c) ViSi/SM4All

These simulators propose to reduce the testing costs by replacing actual home services with virtual objects to visualize the behavior of the Smart Home. Most prototypes are used in functionality tests of Smart Homes with less attention to the users` point of view. On the other hand, there are some researches which aim to simulate and predict occupants' activities in the given building and evaluate the building performance including evacuation, circulation, building control system (Shen et al., 2011). While many of them focus on office environments like Tabak's research (2010) and non-smart environments, the efforts toward developing a UCD system for Smart Homes are rare. V-PlaceSims is one of the rare examples of VR Smart Homes prototype which pays intensive attentions toward users (Lertlakkhanakul et al., 2008). This model enables virtual users as agents to perform specific behaviors autonomously for each spatial building entity. The interaction level between space and users takes place through their avatars. This model explores how to create and implement virtual space as a platform to simulate Smart Home configuration.

a) b)

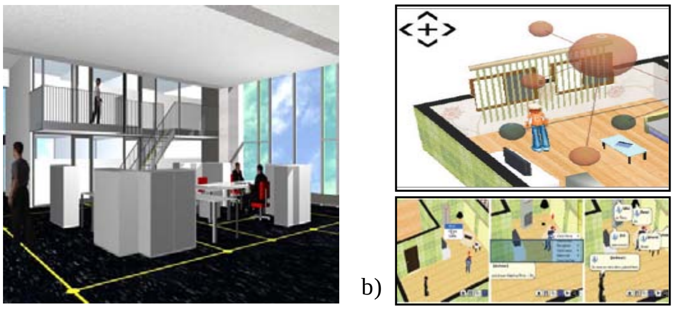


Figure 3. a) Tabak Activity Simulator, b) V-PlaceSims

This model is a good tool for evaluating Smart Home functionality from a technical view. The main focus of this model is automation. It does not support users` real time interaction with wide ranges of smart technologies available in Smart Home. While a Smart Home consists of Ambient Intelligent Space (AmI-S) and Virtual Space (VR-S) combined with Physical Space (PS) (Allameh et al., 2012):

– The Virtual Space consists of ICT appliances such as smart walls and smart furniture that are connected to an information network. It supports information-related activities, such as social networking, tele-shopping, tele-working and tele-learning.

– The Ambient Intelligent Space refers to environments that are equipped with computers and sensors, in such a way that they can adapt to user activities through an automated form of awareness. An example of this space is the context around smart kitchen table. This kind of space will assist daily activities such as cooking and personal activities such as caretaking of elderly and child caretaking.

– The Physical Space is the traditional space where people actually are with their bodies.

Our VR prototype presented here has three added values comparing current simulators:

1) It simulates all three types of space in Smart Home with several smart objects visualising smart walls, smart kitchen table and smart floor.

2) It supports real time interactions. Performing these interactions in virtual tasks improves users' understanding of Smart Home functionalities. This leads to the “paradigm shift in user role from a passive listener to an active actor” (Lertlakkhanakul et al., 2008).

3) It helps users specify their activities in the given new home setting through an Activity Preference plug-in.

Applying this prototype in design process improves users' understanding of the Smart Home and their involvement in the communication with designers.

3. THE STRUCTURE OF A UCD- SYSYTEM FOR SMART HOME

3.1 Smart BIM

To create a UCD-system using for Smart Home design, visualising a virtual Smart Home is needed. To do so, we need to develop an advanced BIM system called Smart BIM which consists of several interactive smart objects. Smart BIM is different from conventional 3D space in that the created virtual space embodies smart objects. It focuses on interactive spaces rather than focusing on digital representation. The smart objects are capable of doing some functions and reacting toward users` interaction according to their available property sets. Hence, we develop a design system with a library of smart components such as smart wall, smart kitchen and smart furniture. The difference between smart technologies and standard building components is that smart technologies interact with the building users. For instance, the definition of a smart wall should not only describe the geometry and material, but also the interaction with its intended users. Smart objects contain their own functions in their property set to interact with users and other objects. We think that designing a smart building requires interactive building components which respond to touch, remote control, motion detection, or whatever method is used to interact. For realistic evaluation of a virtual building model, the smart building components should be able to receive input from the users` interaction and to act accordingly. An example of interactive digital model of a smart wall is presented in Figure 4-a.

3.2 Smart Design System

At the second step, a system is needed which lets users interact with the virtual Smart Home and experience how smart objects respond to typical domestic activities; a system which simulates not only how smart spaces will look like but also how users interact with them. In our proposed Smart

Design System users can perform real-time interactions in a task-based process. We think that when users can directly utilize a task in the virtual model, they can deliver a better comprehension in how smart spaces will be designed, constructed and utilized.

The presented Smart Design System is based on a task-based model in which users can imagine the scheme of their daily activities in the task context and react accordingly. Then the context reacts toward the users` interaction and functions as found in physical smart space. As an example, the subject will navigate to the smart kitchen table (see Figure 4-b). At the spot zone, the virtual mobile phone will pop up. After selection of cooking as the task to be executed, the kitchen table will present a flexible cooking area. The area position and temperature can be adjusted by the subject interactively. At the same time, one of the Smart Walls nearby makes a connection to the social network and another one shows a web site with cooking recipes for users` diet. According to the subject target group, the system is able to active more capabilities. For instance, for an elderly subject, the floor surface will be sensible for falling and the lighting is set to a high level for a better vision.

Through this task-based interaction, users can experience a real time interaction with the Smart Home and gain an overview toward the functionalities of smart technologies. Thereby, an improved understanding of smart technology usage is expected from both end users and designers. In the case of explained experiment, an improved understanding of Smart Kitchen Table capabilities is expected when the subject see the VR environmental reaction toward the cooking task executed by him/her.

For example:

– Safety by experiencing the flexible cooking areas with wireless power and touch screen capabilities,
– Comfort by experiencing seating adjustment capability or wheelchair turning around the kitchen table,
– Sociability by experiencing tele communication capability during the task,
– Health by experiencing online diet recipe presentation, suggested by doctor,
– Protection by experiencing the supportive capabilities such as camera network, alarm facilities, lighting adjustment and smart floor facilities.

3.3 Activity Preferences plug-in

According to figure 1, further development of UCD-system needs contributing users in the design process of Smart Homes. The proposed Smart Design System supports users to have a better understanding of Smart Homes but still cannot support designers to have better overview toward users' actual use. Having a better understanding of how users really act in a Smart Home, designers need a supportive instrument. Accordingly, we add an Activity Preferences plug-in to our Smart Design System. This plug-in inserts several activity lists corresponded to different zones (see figure 4-c).

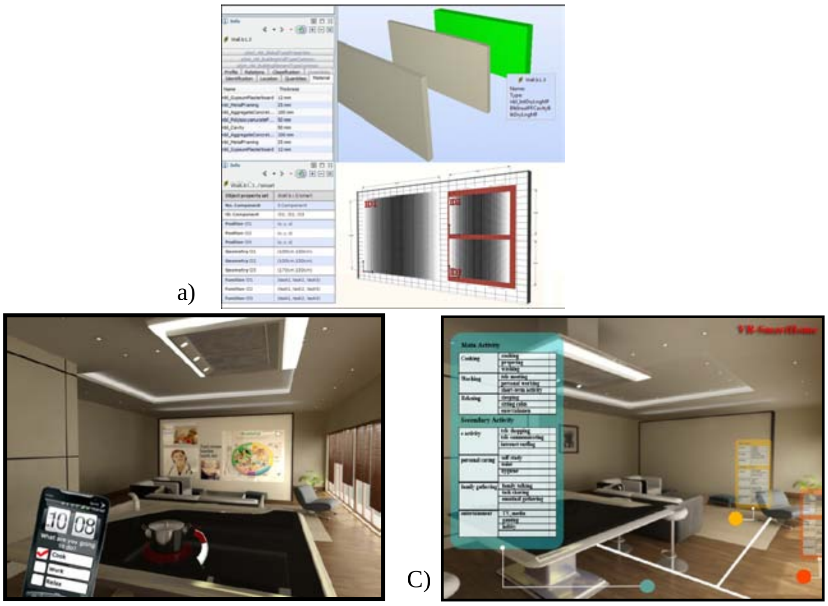


Figure 4. a) Digital representation of Smart BIM (a smart wall), b) Screen shot: Smart Design prototype interface, c) Screen shot: Digital representation of activity lists in zones.

It allows users to specify their Activity-Arrangement and Activity-Schedule in different given time period context. Hence, the users do not perceive the architectural space as an image, but as a composition of various elements in which he/she can select his/her preferred activity. The resulted activity data record is helpful for further design stages. As a result, designers can analyse how people really use the smart technologies before constructions steps. For example:

- The level of multi-functionality for each zone.
- The levels of flexibility for each type of activity.

- The demands of different target groups.
- The amount of time spending in each zone.
- The level of multitasking.
- The types of conflicts among the executed activities in one zone.

4. EVALUATION OF THE VR PROTOTYPE

4.1 The Experiment

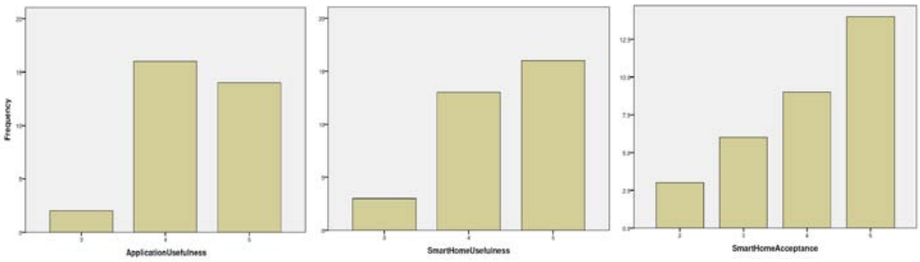
An experiment has been done for evaluating the effectiveness of the presented VR prototype. In this regard, we use a simple questionnaire to measure users` general attitude toward 3 main determinations: Application Usefulness, Smart Home Usefulness and Smart Home Acceptance. For doing the experiment, we use a touchscreen surface to run the prototype. 32 participants interact with the prototype and perform several virtual tasks such as cooking, working, contemplation. Then they fill the questionnaire.

Figure 5. The evaluation experiment which is conducted in ISARC2012 and Super Tuesday event in Eindhoven

4.2 The Findings

As it is depicted in Table1-a, the majority of participants find the VR prototype useful in improving their understanding of Smart Homes. They also have a strongly positive attitude toward the Smart Home usability (see Table1-b). In contrast, participants` responses to Smart Home Acceptance are more varied. Two underlying reasons have been recognized for this finding:

1) This variation in attitudes can be based on other external factors such as personal preferences and needs toward Smart Home. Hence, it is recommended to measure these external factors before doing the experiment.
2) This variation in attitudes shows that although people like the VR prototype and the Smart Home usability, they need time to gain a better understanding of Smart Home and to really accept it. Since the time of experiment is limited, this lack of acceptance period in virtual tasks can be considered as a drawback of our VR prototype. But it can be solved by developing more virtual tasks which cover different given time contexts.



a) b) c)

Table 1. The Frequency table representing participants’ responses to:
a) Application Usefulness, b) Smart Home Usefulness and c) Smart Home Acceptance

Demographic characteristics such as age and living type are also considered in the experiment. Point Biserial Correlation method is used for analysing the correlation among the age groups (<40 and >40) and participants` attitude. But no correlation has been found among the “Age” and “perceived usefulness of VR application”, “perceived usefulness of Smart Home”, “Smart Home Acceptance”. Based on the majority of studies already available in the technology acceptance domain, accepting of new technologies generally tends to decline with age. With increasing age, people tend to become more conservative and will do things as they have always been done. But using new technologies may require the users to alter the way they currently perform certain tasks. However, the outcome is surprising given the result that the age factor has no association with participant`s responses toward Smart Home. Considering this finding together with the outcomes of Table 1, the conclusion is that the majority of participants regardless of their age have a positive attitude toward the VR prototype and Smart Home`s usability after doing the experiment. We consider this as the effectiveness of the presented VR prototype.

Using Spearman correlation analysis for the ordinal variables reveals that:

1. There is a correlation between “perceived usefulness of VR application” with “perceived usefulness of Smart Home”,($p<0.05$)
2. There is a correlation between “perceived usefulness of Smart Home” with “Smart Home Acceptance”, ($p<0.05$)

Correlations

			ApplicationUsefulness	SmartHomeUsefulness	SmartHomeAcceptance
Spearman's rho	ApplicationUsefulness	Correlation Coefficient	1.000	.370*	.265
		Sig. (2-tailed)	.	.037	.143
		N	32	32	32
	SmartHomeUsefulness	Correlation Coefficient	.370*	1.000	.430*
		Sig. (2-tailed)	.037	.	.014
		N	32	32	32
	SmartHomeAcceptance	Correlation Coefficient	.265	.430*	1.000
		Sig. (2-tailed)	.143	.014	.
		N	32	32	32

*. Correlation is significant at the 0.05 level (2-tailed).

Table 2. Spearman correlation analysis

5. CONCLUSIONS

Referring to the findings of the evaluation experiment, the conclusion is that applying a UCD System tool will increase users` contribution in design process. Applying such a system tool in Smart Home design let users explore smart objects and real-time reactions in a virtual model so they can have a better understanding of the design. After experiencing, they can express appreciation, misunderstanding or disapproval considering their needs and preferences and makes suggestions for improvement in design process. Based on the evaluation results, the positive point about the presented VR prototype is that users can easily interact with it regardless of their age or living type. So the Smart Home design does not confront with the challenges of developing real cases or living labs. Using such a UCD system tool in design will result in more realistic Smart Homes offering higher compatibility with users` lifestyles. It is clear to us that in order to design and engineer successful smart environments, it is necessary to have a system which addresses not only technological, but also users` attitude and preferences. We see this as a process of domestication of Smart Home technologies and a process of users` acceptance improvement.

The evaluation conducting in this paper is more related to test the usability of a VR prototype in improving users` understanding of Smart Homes and measuring users` attitude and acceptance level. As a next step, it is necessary to evaluate the usability of this VR prototype in design practices of Smart Homes. We believe that the proposed system is an assessment toolset for Smart Home designers to adjust the spatial/technical layout of the Smart Home such that it accommodates the user's lifestyle optimally.

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