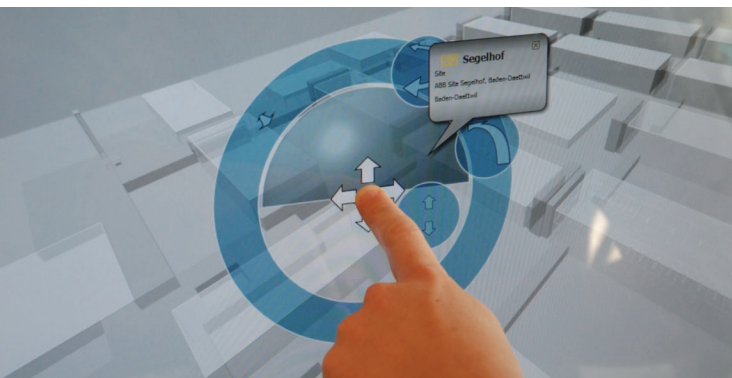


On-Screen Navigation for 3D Interaction on Multi-Touch-Displays

Aspects making the SGD navigation
more intuitive



**Thesis – Master of Advanced Studies in
Human Computer Interaction Design**

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Abstract

A usability test with novice users was conducted on an initial and an improved navigation concept. The tested system was a multi-touch-display using infrared technology with a limit of detecting two touch-points. The task for participants was to navigate through a virtual environment using either a widget or gesture-only based navigation concept. The goal of these tests was to assess which aspects influenced intuitiveness of a system for novice users as well as to collect user expectations. The results of these tests indicated that further investigations would be necessary in certain domains as some conclusions were based on assumptions. However, this thesis gives good insights on different aspects and gives further interesting areas to be explored.

Keywords

gestures; intuitiveness; learnability; multi-touch; navigation; novice users; touch-screen; usability; virtual environment; widget

Declaration of Authorship

We declare that we have developed and written the enclosed thesis completely by ourselves and have not used sources or means without declaration in the text. The Master Thesis has not been used in the same or in a similar version to achieve an academic grading or has been published elsewhere.

Zurich, 19.01.2012

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1 Introduction

This document represents the work of our master thesis. After an introduction, chapter 2 outlines the theoretical aspects of 3D interaction within the context of the subject and brings up questions that are of special interest. The team's approach and used methodology is explained in chapter 3.1. The evaluation and results of the initial solution are described in chapter 3.5 and the proposed improvements in chapter 3.6. The evaluation of the proposed improvements is documented in chapter 3.7, which leads to conclusions and discussions with regard to the theoretical aspects in chapter 4. A reflection on the approach and used methods is given in chapter 5. All relevant data gathered throughout this project can be found in the *Addendum*.

Readers who are only interested in the results and conclusions are advised to read chapter 4. For anybody who likes to understand the full complexity of the subject a full study of this thesis is advised.

1.1 Project Definition

This master thesis concludes the MAS study in Human Computer Interaction Design. It was completed by a team of three students within a time frame of nine months and approximately three hundred working hours per student. This project was sponsored by ABB Switzerland and supported by a coach of the university.

1.2 The Subject

ABB Switzerland has sponsored the development of a Smart Grid Demonstrator (SGD) which is setup at the Segelhof, ABB's corporate research center (CRC) in Baden-Dättwil, Switzerland. More than a year ago, a range of sensors and actuators were installed, which return continuous measurements, reporting energy consumption, production, and environmental data of the CRC Segelhof. A graphical user interface (UI) prototype was developed to present the stored data – the Smart Grid Demonstrator (SGD).

The user interface presents the measurement data in different ways:

- A hierarchical tree structure lists the devices and measurement points
- Data is organized according to their location
- Data points are assigned to devices, devices are located in rooms that are part of floors within a building
- The same hierarchical data structure is also presented as a 3D model, representing the approximate geometry of the site

All data is time-based and stored in a database. A global time is set to choose the current state and can either track the present (e.g. show real-time data) or provide animation of past measurements. The time is controlled with a dedicated control.

The SGD was developed to present the smart grid matter in a playful way. Using a huge touch-screen, mounted on a wall in the lobby of the Segelhof (see *Figure 1-1*), the intention was to attract visitors and customers waiting in the lobby, to explore the 3D virtual environment of the smart grid setup.



Figure 1-1 Smart Grid Demonstrator

1.3 Problem Domain

The SGD is intended to be used primarily by novice users to explore the smart grid matter and secondly by expert users giving demonstrations to visitors. Novice users can be visitors of the Segelhof site, who have about ten minutes spare time while waiting to be picked up. For this study only novice users are considered whereas expert users are out of scope. The user interface of the SGD should allow the user to navigate within a virtual environment in a 3D world.

According to the sponsor the SGD should be usable in an effective and intuitive way. Besides, it must be operated without mouse or keyboard. Any design change proposals must build upon the existing software and hardware.

A prototype implementation provides all the basic functionality. The SGD user interface is said to be stable and supports all currently identified tasks using a multi-touch-screen. Though several aspects are missing or offer obvious space for improvement:

- The usability of the interface has not yet been evaluated
- Certain actions are difficult to conduct (e.g. buttons are small and therefore difficult to hit given the limited precision of the touch interface)
- 3D navigation works but might not be fully intuitive

Therefore the requirements for novice users have to be acquired first followed by a usability evaluation of the current solution. Based on these results design changes should be proposed which will then be implemented and reevaluated.

1.4 Relevance of this Work

Contribution of this Work to the Current Research

In a first respect this thesis gives an overview of the relevant studies found in scientific articles for on-screen navigation on multi-touch-displays with 3D interaction. By evaluating the SGD prototype with usability testing and then designing solutions for improvements and finally evaluating the improved and implemented software version, we demonstrate how to apply user centered design (UCD) techniques in a challenging field. It is challenging from the UCD perspective because the SGD is not yet a product but a research project with only vague ideas about the users and their tasks. On the other hand 3D techniques that are used in virtual environments are still in research status while established solutions that are implemented in products are rare.

This work demonstrates what UCD methods are useful for evaluating and improving 3D on-screen navigations in the described context. It shows what measures are appropriate for making a system like the SGD usable in an intuitive way for novice users. In particular this thesis illustrates pros and cons of solutions using navigation widgets or gestures-only. It discusses aspects like *scene-in-hand* and *eyeball-in-hand* metaphors, pivot setting, mapping of user navigation to the corresponding virtual model movements as well as view perspectives. Furthermore it explains the impact of hardware reliability to the learning curve of on-screen navigations. Last but not least a wide field of further investigations is listed, which are based on the findings and conclusions gained in this project.

Deliverables

The following deliverables are included with this thesis:

- State of the current research relevant to this context
- Pre-definition of users' needs (provisional persona)
- Definition of usability goals for the pre-defined users
- Usability report of current prototype
- Design proposals to improve current prototype
- Evaluated design proposals for the SGD
- Reflection on used UCD methods
- Open questions for future investigations

Motivation of the Team

Already at the beginning it was obvious that this project would be provoking. The project team took it as a challenge to see what UCD methods are useful and, if necessary, how they can be adapted for evaluating and improving a prototype like the SGD, which was developed for research purposes. In addition to that, questions of 3D virtual environments were new to the project team but promised to be very interesting. Due to this fact the project team was highly motivated to work this subject in. Furthermore knowing that the professional background of the team members was diverse but can complement one another was an important aspect too.

And lastly it was a great opportunity to contribute valuable findings and conclusions not only to the UCD community but also to the research field of 3D virtual environment interactions.

1.5 Timeline

This article explains the project phases in short. For a detailed view of the project timeline a *Gantt Diagram* can be found in the *Addendum*.

This project was fired off by signing an agreement with the university and the sponsor followed by a kick-off meeting at the sponsor. First a requirement analysis took place that lasted around six weeks. In parallel to this literature research was done for two months. After the requirements analysis the first usability evaluation was conducted, where planning and execution took one month. The following analysis of the gathered data and the design phase for improvements lasted about seven weeks. The implementation of the proposed solutions took six weeks. The evaluation could be carried out within one week right after the implementation. Data analysis then took another six weeks. The documentation of findings and draft writing of the thesis started while data analysis of the second usability evaluation was still in progress. Writing the thesis took more time than planned and went on for nine weeks. Proofreading, wrapping up and printing out of the thesis took another three weeks.

2 Theoretical Aspects of Virtual Environments

This chapter gives an introduction into 3D topics which are relevant in this context as well as taxonomies on how intuitiveness is defined and evaluated. Theses and arguments raised in this chapter will be discussed later in chapter 4 where the theory outlined here is compared with the practice described in chapter 3.

2.1 Intuitiveness – Definition and Method of Evaluation

Intuition seen from the psychological perspective is based on experiences humans gain throughout their lives. Intuitive thinking is opposed to logical thinking and can hardly be controlled by consciousness (Häcker, et al., 2004). Intuition is rather grounded on a cumulative treasure trove of experience than based on explicit memory of a certain incident. While difficult to describe it is intersubjective and often not comprehensible (Klein, 2003). According to Klein intuition helps to recognize and compare patterns. The following quotation of Tad Coffin (2011) fits nicely to the definitions above and may give a hint how intuitiveness is seen in this work: “By intuitive navigation, I mean some sort of menu, map or list that is instantly understandable to most visitors to your web site”.

Measuring the intuitiveness of a web site or even a 3D graphical Interface like the SGD does not seem to be easy. Nevertheless intuitiveness can be seen as a collective term of the following usability criteria, defined in ISO standard 9241-110: Self-descriptiveness, conformity of expectation and learnability. Luckily these usability criteria can be measured with the help of the ISO standard questionnaire. Those three dimensions were explicitly measured on both usability tests as described later in this document. On the other hand specific results of the usability test (see “*Usability Evaluation 1 - User Expectations*” in the *Addendum* and *Figure 3-28*) as well as the interviews can give implicit indications of intuitiveness.

2.2 Overview of 3D Technologies, Tasks, and Multi-Touch-Displays

This chapter outlines some aspects around three-dimensional (3D) environments which are important to understand. As there are many books and papers available on 3D interfaces, 3D interactions, virtual environments (VE), augmented reality (AR), data gloves, and many more topics, it is important to distinguish between them, understand what is meant and what is important in this context.

2.2.1 User Interfaces and Devices

For a better understanding of 3D VEs we will first look at the different kinds of output and input devices and then jump to the possible tasks and scenarios in the VEs.

A view into some studies and publicly available software (SW) will give an insight of what kind of research and work has been done so far.

Output Devices

An output device can either be a visual, audible or haptic device that stimulates the human sense. A visual output device is usually called a display and can be either

- a) Stationary (e.g. flat screen or hemispherical projection) or
- b) Head-mounted (e.g. pair of glasses)

on which a VE is displayed. The listing of devices is not conclusive but indicates the most common display types used.

The more the amount of physical space around a user is filled with visual images the greater the degree of immersion is. Therefore the more the user feels part of the VE itself. The choice of display can therefore be based on the degree of immersion that needs to be reached. Head-mounted displays can be used for immersive VEs as the real world is totally blocked from the users' view. However, common displays can also reach a high level of immersion such as used in flight simulators *et al.* The terms 'mixed reality' or 'augmented reality' are used when synthetic information such as in head-up-displays (HUDs) is displayed in addition to the real world.

In the context of the SGD there is only very little degree of immersion that needs to be reached. Therefore a common stationary visual display such as used for desktop systems to display 3D data is used.

Since no audible or haptic senses are stimulated by the SGD these output devices will not be looked at in detail.

Input Devices

Input devices are the only means for users to interact with the output device or the information that is displayed on them. The characteristics of such input devices are very broad. Some of them track motion, visual, tactile or acoustic signals or change in electric current. The most common ones are: mouse, joystick, keyboard, touch-sensitive pads/screens.

One of the key characteristics of input devices is that some devices measure the position, movement and velocity of motion from the users' hand or finger such as mice, motion trackers, and touch pads/displays (isomorphic devices). Other devices track the force that is applied to them such as seen with most joysticks and keyboard incorporated miniature joysticks (isometric device). A study (Zhai, et al., 1993) has shown that isomorphic devices were more effective for speed and acceleration control (rate) and isometric controls were preferred for positioning and manipulation tasks (positioning control).

Looking at the most specific characteristics of such devices this would most probably be the *degree of freedom* (DOF, refer to chapter 2.2.2) each of the devices is capable of capturing. The amount of DOF gives an indication on how complex the device is and how powerful it is on accommodating various interaction techniques. Following table (Table 2-1) gives a rough taxonomy of possible DOF based on typical gestures applied to the input devices, though different taxonomies exist.

Table 2-1 Input devices and their approximate DOF

Type	DOF	Typically Mapped To
<i>Slider</i>	1	move x
<i>Mouse</i>	2	move x, y
<i>Trackball</i>	2	Rotate ϕ , θ
<i>Joystick</i>	2-3	move x, y (and twist θ)
<i>Touch-screen (1 touch-point)</i>	2	move x, y
<i>Trackers</i>	6	move x, y, z; rotate θ , ψ , ϕ
<i>SpaceMouse, SpaceBall</i>	6	push x, y, z; twist θ , ψ , ϕ
<i>Touch-screen (2 touch-points)</i>	~ 6	move x, y (with one or two fingers), pinch and twist (with two fingers)
<i>Touch-screen (3 touch-points)</i>	~ 10	move x, y (one, two, or three fingers), pinch and twist (two or three fingers)

Touch-sensitive displays in detail may increase the amount of DOF significantly as the capability of capturing touch-points increases. Given this, even a multi-touch-screen with only two touch-points is capable of interacting with demanding systems like 3D VEs. According to Garner (Garner, 1974), the perceptual structure of 3D manipulation consists of six integrated DOFs, therefore a multi-touch-display with a minimum of two touch-points should be capable of navigating through a 3D environment. A study looking into and comparing one-, two- and three-touch techniques (Hancock, et al., 2007) has proven that a higher number of touches allow more natural and flexible interaction. Also Hancock *et al.* have seen that people are not only capable of simultaneous control of rotation and translation, but prefer it.

However the numbers of DOF listed in *Table 2-1* do not take into account the different ways on how touch-points and gestures are mapped and used in conjunction with other available functions such as widgets.

For the SGD a multi-touch-display is used as input device with the capability of capturing a maximum of two simultaneous touch-points. Unfortunately there is very little literature on this particular application with this technology (Chow, et al., 2011) and (Martinet, et al., 2010). The study of Fu, Goh and Ng (Fu, et al., 2010) on using multi-touch techniques proved that multi-touch gestures are very intuitive for users, requiring only very little instruction or practice. Another study using multi-touch-displays to position objects in a virtual world compared classic multi-viewport against single-viewport systems. The introduced *z-technique* (Martinet, et al., 2010) using a single-viewport was preferred by 6 of 8 participants against the classic CAD approach using four viewports, where one viewport is used for displaying the model in perspective and the other three viewports for displaying top, front and right view of the model.

2.2.2 Widgets

When users work with VEs they often do not interact directly with the objects that are displayed but use specialized UI menus that give them advanced functionality to work with. These UI menus are called widgets and have been very vastly used for desktop applications such as seen in *Figure 2-1*.

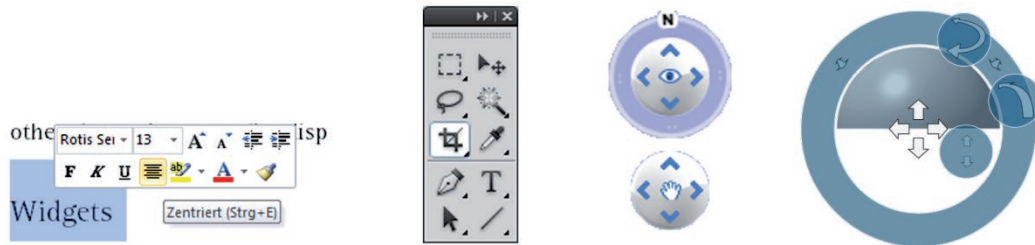


Figure 2-1 Widgets from left to right: MS Word, Adobe Photoshop, Google Earth, and SGD

The basic approach of widgets is to give users a certain set of controls to manipulate objects. In VEs these widgets provide controls for specific manipulation such as for rotations, translations, scaling, and more. The advantage of such widget is that users can quickly choose and change between the different manipulation options. This is why widgets have become the standard interaction technique for most desktops as well as immersive VEs. However, widgets do add a certain degree of visual clutter and need to be carefully designed and positioned.

2.2.3 Degree of Freedom (DOF)

The DOF defined by Doug A. Bowman (Bowman, et al., 2005) is: *“The number of independent dimensions of the motion of a body. DOF can be used to describe the movements of input devices, the motion of a complex articulated object such as a human arm and hand, or the possible movement of a virtual object.”*

As an example, trains which are bound to their tracks only have 1-DOF, meaning they only have the freedom to travel forward and backward on a given path. A mouse already has 2-DOF which allows moving freely on a 2D plane. A car has 3-DOF as it can move forward and backward as well as turning around one of its axes, but it is also able to skid. Looking at aero planes 4-DOF are present namely the rotations around all axes as well as flying forward. Sway or heave manipulation is not possible in a direct manner.

In the context of objects in a virtual world there are usually 6-DOFs namely the transitions along the coordinates x, y, and z as well as the rotation around its three axes. Looking at the virtual world such as provided by the SGD, a system is given that allows to rotate and move the virtual world (represented as the scene in *Figure 2-2*) in relation to the viewpoint as well as rotate and move the viewpoint (presented as the eyeball in *Figure 2-2*) in relation to the virtual world. These different points of view can be seen as metaphors *eyeball-in-hand* and *scene-in-hand* which are explained in chapter 2.2.5.

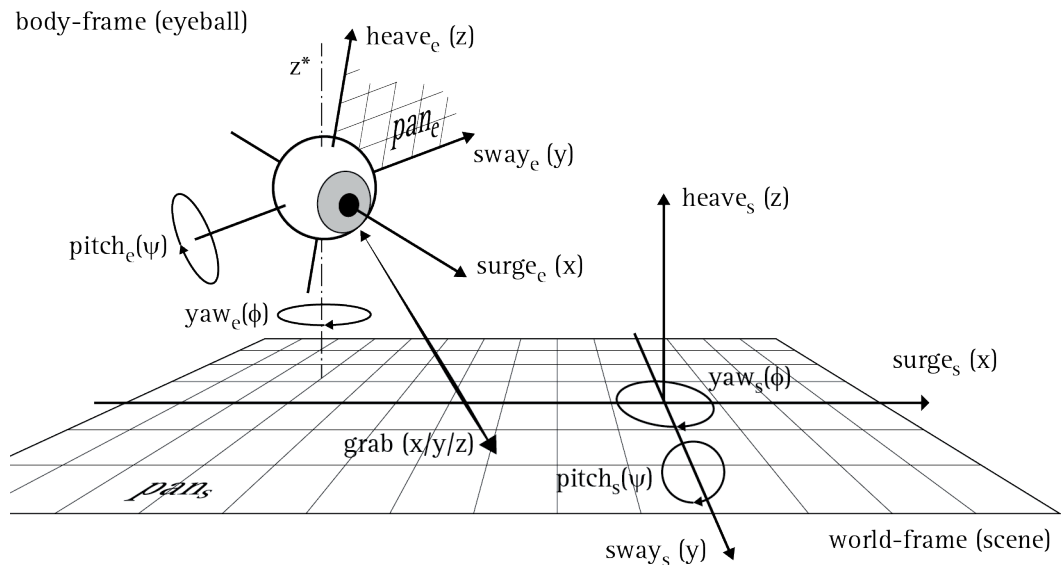


Figure 2-2 Representation of the degrees of freedom depending on the point of view

In this document the naming convention for manipulation of rotations and translations is as follows:

1. Surge (translation along the x-axes; sometimes also referred to as zoom)
2. Sway (translation along the y-axes; also referred to as pan when combined with surge or heave)
3. Heave (translation along the z-axes; also referred to as elevation)
4. Pitch (rotation around the y-axes; also referred to as tilt or nick)
5. Yaw (rotation around the its z-axes; also referred to as rotation)
6. Grab (translation on a beam between the viewpoint and a point in the VE; also referred to as zoom)

These rotations and translations use 5-DOF for each metaphor plus the additional *grab* manipulation, which is a combined-manipulation shared between the metaphors, add up to a total of 11-DOF. How many and which DOFs are needed for the SGD will be looked at in Chapter 3.

Some important remarks about the terms:

- Surge_e or grab is often mistaken for zoom. Zooming is by definition a manipulation of the focal-length only. Hence, if zoom is mentioned in this document or its attachment, surge_e or grab is meant.
- Pan is a term used for describing a combined 2-DOF operation such as heave/sway or sway/surge, i.e. moving along a 2D pane as visualized in Figure 2-2.

2.2.4 Tasks and Scenarios in Virtual Worlds

Three-dimensional environments and the tasks that can be completed can be very different and complex in detail, but in general there are two different environments: manipulating/selecting and traveling.

Manipulation and Selection Tasks

Manipulation and selection tasks are object-related such as in e.g. interior design software or special 3D virtualizing tools like *Cinema 4D*. The environment is usually

static and cannot be changed, but the objects within the environment can be manipulated. Looking at the tasks involved they can be broken down into the three distinctive tasks selecting, positioning, and rotating referred to as “*canonical manipulation tasks*” (Bowman, et al., 2005).

1. *Selection* is a task of choosing between different objects available
2. *Positioning* is the task of positioning the selected object within the 3D environment
3. *Rotating* is the task of changing the orientation of the selected object

Looking at the SGD there are none of these pure object manipulation tasks, although the whole scene can be selected, positioned, and rotated. Distinctive objects can be selected to display contextual information but none of these objects can be positioned or rotated individually. Manipulating individual objects within VEs will therefore not be further investigated.

Traveling Tasks

Traveling tasks are the main tasks which are executed in the SGD. They help users to reach their specific goals such as freely exploring the scene or search for specific information and details of the scene. Traveling techniques should therefore support continuous and direct manipulation of the viewpoint.

Traveling large distances and maneuvering within small spaces have very specific and therefore contrary goals. Maneuvering is a task to manipulate the viewpoint very exactly and minute whereas traveling large distances is done very quickly and rough. Manipulation techniques should therefore support both tasks equally. As Stoev *et al.* mentioned: “*The scene-in-hand metaphor is more appropriate for traveling to far destinations, while the eyeball-in-hand metaphor is more suitable for adjusting the viewpoint at the current location.*” (Stoev, et al., 2002)”. Both metaphors are described more in detail in chapter 2.2.5.

The subtasks of traveling are of course a lot subtler than mentioned above. An overview of these is provided by the following taxonomy (Bowman, et al., 1998) and is divided into three subtasks “*direction/target selection*”, “*velocity/acceleration selection*”, and “*input condition*” though this is more related to head tracking systems in immersive VEs. Another taxonomy that seems to be more relevant for the SGD is the following composition in *Figure 2-3*. This is because it is more related to *desktop 3D* rather than *VEs* and it explicitly mentions viewpoint orientation.

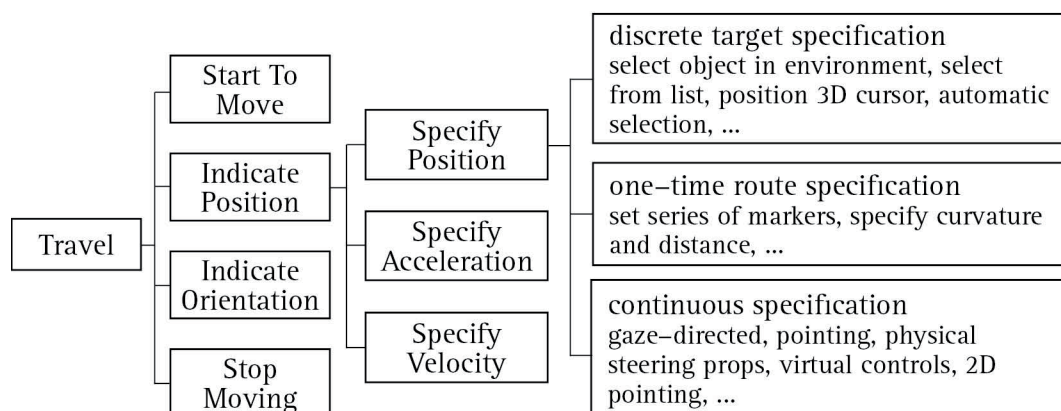


Figure 2-3 Taxonomy of virtual travel techniques, with detail shown for the ‘specify position’ according to (Bowman, et al., 1999)

2.2.5 Navigation Metaphors Used in Virtual Environments

Navigating through VEs and manipulating objects are two very distinct manipulations. In the first case the viewpoint is manipulated while in the second case an object is manipulated. Some refer to manipulation of the viewpoint as the *camera* or *virtual-eye* (Hand, 1997) metaphor. In this document it will be referred to as *eyeball-in-hand* instead, and the manipulation of the object as *scene-in-hand* (Ware, et al., 1990) for ease of use. Ware and Osborne also defined a third metaphor, the *flying-vehicle-control*, but this is very similar to the *eyeball-in-hand* when looking at the viewpoint manipulation.

- a) In the *eyeball-in-hand* metaphor the viewpoint is manipulated and can also be looked at moving a camera around in the scene as well as rotating the eyeball/camera around its own axes. The outcome of this kind of manipulation is like moving within a scene such as walking, flying or swimming.

The user's model is that of placing an eyeball with respect to an invisible model. What the eye sees is only available via the monitor (Ware, et al., 1990).

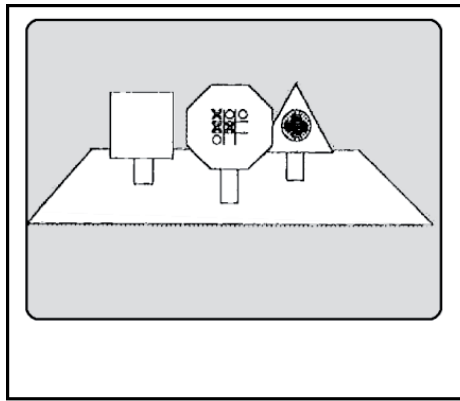
- b) In the *scene-in-hand* metaphor an object or the whole scene can be manipulated while the viewpoint is static.

The user's model is of a direct linkage. Translations and rotations of the control device result in corresponding translations and rotations of the scene (Ware, et al., 1990).

Ware and Osborne evaluated the metaphor *eyeball-in-hand* using a *Polhemus* to position the eye in an invisible scene in front of the monitor and the metaphor *scene-in-hand* using a 3Space bat to directly manipulate the scene at its center. The conclusion was that there is neither a real winner nor a real loser. However, depending on the task which had to be completed the preferences were pretty clear. While the *cube* task was preferably used by *scene-in-hand* metaphor, the *maze* task was preferred using *flying-vehicle-control* or the *eyeball-in-hand*. However, it has to be taken into account that the technical setup as well as the implementation of the pivot for *scene-in-hand* as used by Ware and Osborn substantially differs from the SGD.

2.2.6 Navigation Interactions and Gestures

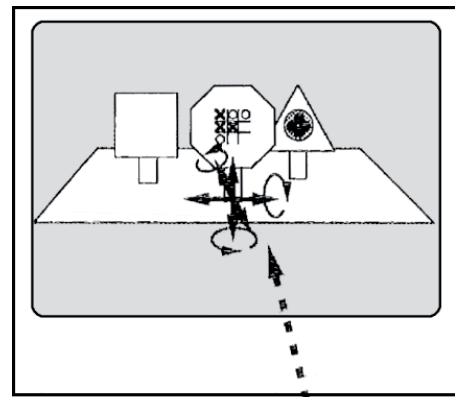
The SGD is a desktop or wall-mounted system using a common multi-touch-display, therefore there is no immersive VE and no special interactions involved. Also it has to be taken into account that the SGD does not require manipulating individual objects. These facts are crucial to understand and distinguish from, as much literature available is based on either immersive VE, 3D (spatial) input devices or individual object selection and manipulation tasks. Therefore this document will give insights into single and multi-touch gestures-only and will not go any further into input devices available.



Virtual Environment



Figure 2-4 Eyeball-in-hand metaphor



Control Linkage

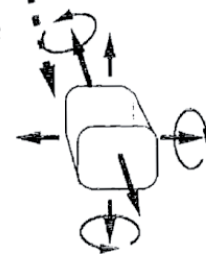


Figure 2-5 Scene-in-hand metaphor

The following articles listed below demonstrate different approaches on how multi-touch-displays have been used to interact with 2D/3D data or VE.

A Public Multi-Touch-Display

“Everything starts with one finger. Users were most likely to attempt to manipulate objects with one finger initially, especially when not influenced by other users.” (Jacucci, et al., 2010). This was a statement after studying the approach of visitors using a public multi-touch installation.



Figure 2-6 Visitors trying different techniques to learn interactions at a public multi-touch installation

The gestures implemented in this installation, depending on the object manipulated, were:

1. Spin/move – moving fingers on the surface
2. Resize/open/close – two or more fingers moving in opposite directions
3. Rotate – two or more fingers moving in a circular fashion, and
4. Throw – a rapid dragging action
5. Play/stop/open/close - touching the surface and holding the finger down for 2 seconds

The issue they struggled with most was the mapping gestures when the DOF of VE was increasing.

A Public Multi-Touch Table

A different field study was conducted in an aquarium to see how visitors interacted with a multi-touch table. The study has shown that there are many natural gestures for a given intended action, but the choice of the interaction was influenced by prior interaction context as well as their social context. Hence, gestures are not to be seen isolated but in context with previous and subsequent interactions, age and the users' intention (Hinrichs, et al., 2011). A collection of some 2D gestures that had been tried are shown below. However, it has to be taken into consideration that the system was horizontally positioned instead of vertically and the system (Microsoft Surface) supported touch-points greater than two, with regard to the SGD.

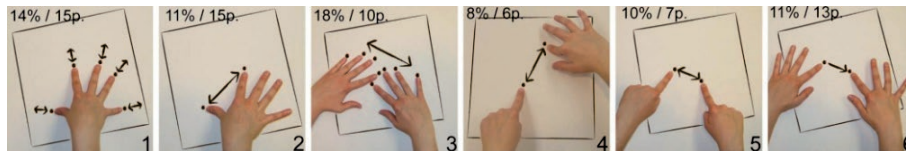


Figure 2-7 Gestures applied to the enlarge/shrink action

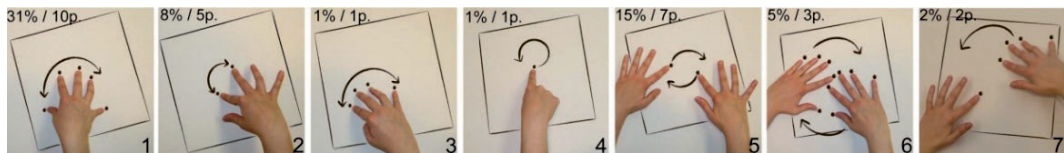


Figure 2-8 Gestures applied to the rotate action

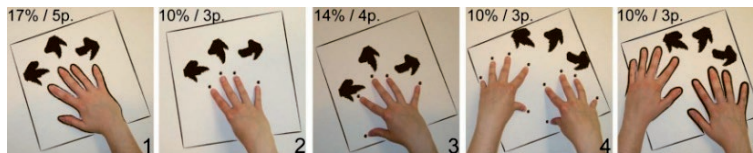


Figure 2-9 Gestures applied to the sweep action

Traveling Through a VE Using a Multi-Touch-Screen

Another recent research wanting to use 2D gestures on multi-touch-displays seems very promising as the task could be very similar to the ones seen in the SGD (Chow, et al., 2011). The plan in this study is to look into the aspects of traveling and way-finding in 3D VEs. However, results of their work have not yet been published.

Google Earth on Apple's iPhone

The iPhone version of Google Earth v.3.2.0, although not a true VE since it basically is a 2D map with additional 3D aspects such as geographical projections and 3D objects, is an interesting example. Most interesting aspects are that the two metaphors, *scene-in-hand* and *eyeball-in-hand*, are implemented. Although *heave* is not directly supported in any of the gestures, the altitude can be changed by pitching the viewpoint and surging out. This is not effective but might be intuitive for most users, though would need to be further investigated with them. Looking at the implementation, the following four gestures were mapped to the 6-DOF:

1. Swiping with one finger in all directions is mapped to the scene, moving it in the respective directions
2. Pinching with two fingers is mapped to the viewpoint and results in surging to the middle of the screen (see Figure 2-10 a) and b). Depending on the pitch of the viewpoint, the behavior can either be looked at as 'zooming' into a specific area or flying over the scene

3. Twisting two fingers is mapped to the scene and results in rotating the scene, while the pivot is set either in the screen's center or in the middle of the lower end of the screen and the horizon, depending on the pitch of the viewpoint (see *Figure 2-10 c and d*)
4. Swiping to finger parallel is mapped to the viewpoint and results in changing the pitch and yaw

Further interesting points are:

- The pinch and twist gestures are combined, hence enabling the user to surge and yaw the scene at the same time
- Rotating the viewpoint is done at a fixed angle of 90° relative to the scene rather than to its own axis
- The two metaphors can be implemented next to each other providing as much DOF as possible

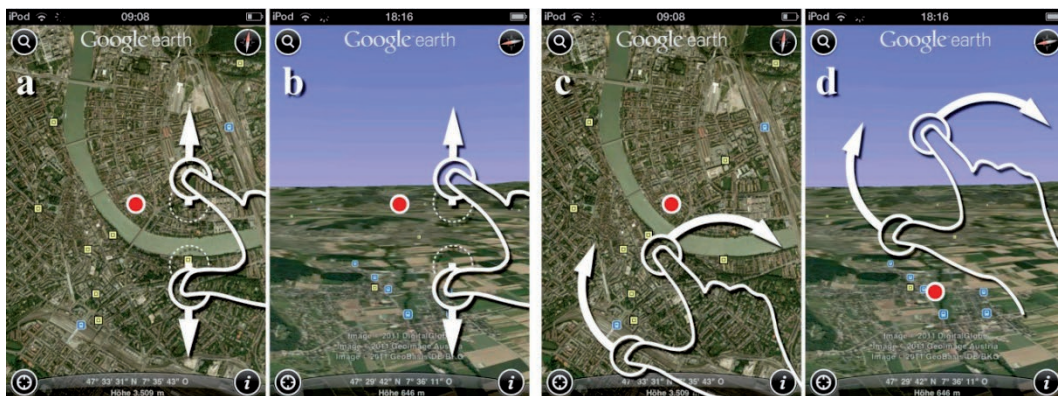


Figure 2-10 A screenshot of Google Earth taken from an iPod indicating a), b) center of surge and c), d) center of yaw depending on the viewpoints pitch

Navigation Spatial Data Using Hands and Feet

The research of this study showed the potential of multi-touch-screens for interacting by hands with an additional device for interaction by feet. The conclusion of the study has shown that an additional foot-device can have a huge potential with navigating in special domains or other domains using a 3D space to organize data (Schöning, et al., 2009) .

The foot-device was used for continuous panning by leaning to either side. By leaning forwards the pitch could be controlled. Surging was performed by either moving two fingers or hands apart or pointing to a location whilst leaning forward on the foot-device. In their setup they could distinguish a total of eight directions.



Figure 2-11

User is interacting with both hands and feet with a virtual globe using a large size multi-touch wall. User is standing on Sony's Wii balance board (marked with yellow circle)

2.2.7 Exploring Large-Scale 3D Astrophysical Simulations

The most challenging issue with this research (Fu, et al., 2010) was implementing a solution for users to navigate through the vast spatial environment of the astrophysical space, as most of it is empty. Another challenge with this study was the fact that the users were novice with little experience navigating with virtual navigation on multi-touch interfaces.

The hardware-setup was similar to the one used with the SGD concerning to the technology used for detecting multiple finger contact. However, the number of touch-points was not restricted to a maximum of two.

Regarding interaction, they were able to identify six frequently used tasks to navigate through the large-scale 3D astrophysical simulator:

1. Object selection on screen, e.g. a planet or star
2. Rotating the 3D world around a center, e.g. the sun
3. Camera movement to/from a desired visible waypoint
4. Rotating the 3D world around a selected object
5. Power-of-ten style movement across different scales
6. Camera panning

Following gestures were mapped to the DOF:

1. Swipe rotated the scene around a default center/star (see *Figure 2-12*)
2. Pinch triggered the camera to grab the selected point (midpoint between two fingers, indicated by a cross-hair icon) (see *Figure 2-13*)
3. Holding down one finger and swiping with the second finger triggered a rotation around the resting finger (see *Figure 2-14*)
4. Swiping with multiple fingers triggered the viewpoint to pitch and yaw, a circling gesture with multiple fingers triggered the viewpoint to roll (see *Figure 2-15*)
5. Holding down two fingers and swiping with a third finger triggered the camera to surge to the selected point with the power-of-ten (see *Figure 2-16*)

An interesting statement made by the authors was that they decided not to move certain functionality such as the power-of-ten ladder to the edge of the screen because of *interaction locality*. With interaction locality they meant that the function should be initiated at the current location rather than at a pre-defined screen location.

All participants rated the experience positively, hence the authors suggest such forms of interacting suitable for an interactive digital planetarium as well as other similar spatial environments such as bioinformatics and molecular sciences for general public.

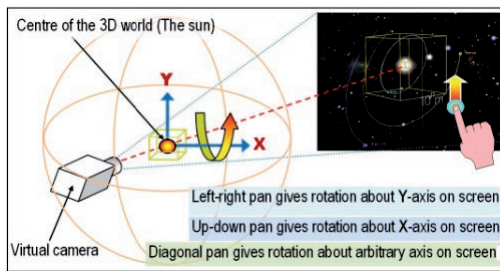


Figure 2-12 Gesture for rotating the 3D VE around its default center, i.e., the sun

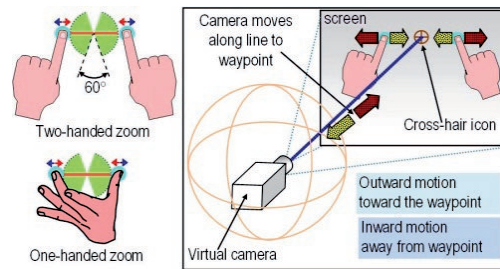


Figure 2-13 Gesture for surging to a specific point

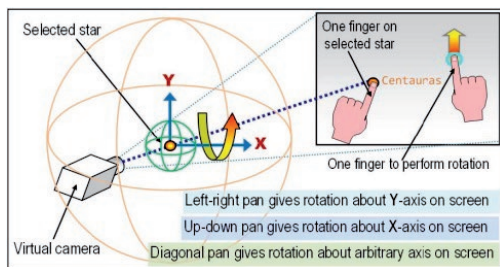


Figure 2-14 Gesture for rotating the 3D VE around a selected star

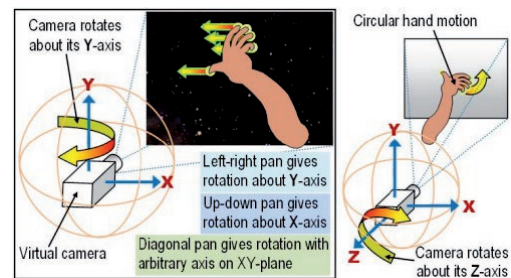


Figure 2-15 Gestures for rotating the viewpoint

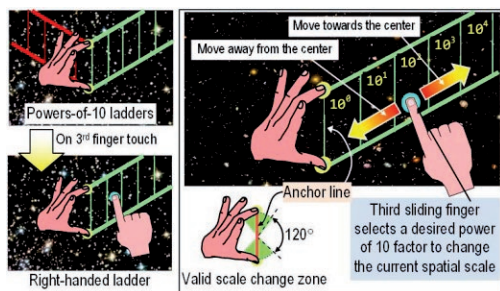


Figure 2-16 Gesture for surging at the power-of-ten

2.3 Known Issues Navigating through and Interacting with Virtual Worlds

Navigation in a 2D world is a relatively straight-forward process and can be mapped to few input controls whereas in 3D, both way-finding and movement require a lot more mental and physical action (Darken, et al., 1996).

Freedom of Control

To overcome some of the issues when maneuvering through virtual worlds such as degenerated axes (Phillips, et al., 1992), hence losing orientation when the viewpoint is set to a sub-optimal position, the freedom of navigation can be decreased as shown in the table below (Nurminen, et al., 2008).

Table 2-2 *Maneuvering classes in decreasing order of navigation freedom*

Maneuvering Class	Freedom of Control
<i>Explicit</i>	The user controls motion with a mapping depending on the current navigation metaphor.
<i>Assisted</i>	The navigation system provides automatic supporting movement and orientation triggered by features of the environment, current navigation mode, and context.
<i>Constrained</i>	The navigation space is restricted and cannot span the entire 3D space of the virtual environment.
<i>Scripted</i>	Animated view transition is triggered by user interaction, depending on environment, current navigation mode, and context.
<i>Automatic</i>	Movement is driven by external inputs, such as a GPS device or electronic compass.

These classes of *freedom of control* can be seen in many known applications and games.

In the desktop version of *Google Earth* many of these classes can be identified:

- When searching for a location, a scripted class is used to perform the relocation of the viewpoint
- When moving to a lower altitude, the user is assisted by automatic switching to a horizontal view and finally asking to switch over to a different metaphor, such as Street View or Ground View. These metaphors are then constrained to specific aspects such as altitude, a specific path or angle of view

This thesis will investigate to what extent the classes mentioned above are applicable or not.

Interaction Locality

As Fu, Goh, & Ng (Fu, et al., 2010) described in their large scale navigation techniques, there are some interactions that need to be performed at the locality chosen by the user. The advantage is that the behavior is performed as expected by the user. If a control to interact with is set elsewhere on the screen, the point of control (pivot) has to be predefined by the system. Predefined pivots are usually set at the screen's center where the interactions are performed. This can be unsatisfactory as the behavior for operations such as *surge_c* (zoom) will be different than expected.

Setting a Pivot

In the *eyeball-in-hand* metaphor the position of the pivot is clear, as it is in the eyeball itself. Therefore, all rotations and transitions are relative to the eye respectively to the viewpoint. When using the *scene-in-hand* metaphor the pivot has to be set manually. In the *scene-in-hand*-setup used by Ware and Osborne (Ware, et al., 1990), the pivot was set by default to the center of the scene which was one of the main reasons participants had difficulties with this metaphor in the *maze-task*. In the setup of the large-scale 3D astrophysical simulator, the pivot was also set to a default position (the sun or the earth), but could also be chosen by the participants themselves. They could select another point such as another star or planet (Fu, et al., 2010). Enabling a manual positioning of the pivot enhances the interaction with the scene and therefore adds another degree of freedom to the user.

In the SGD, a manual selection was added for the freedom of interaction. Similar to Allan Bier's study *skitters and jacks* (Bier, 1986), a ray-casting technique was used to set the pivot (*jack*). In this situation a ray is shot from the viewpoint to the selected touch-point on the screen and the pivot is set to the nearest object in the scene intersecting with the ray.

2.4 Questions Which Are Of Special Interest

Looking at the problem domain and the requirements that were outlined and set by the stakeholders, there are some points of interests that need to be investigated in more detail with regard to intuitiveness and learnability.

2.4.1 Are Interactions More Intuitive and Comprehensive with or without Widget?

The current solution for the SGD is implemented with the widget as described by Martin Naef and Ettore Ferranti (Naef, et al., 2011). As the widget is not thoroughly tested with novice users the aim is to find out to which extent the intuitiveness is leveraged in contrary to a gestures-only solution with no widget or UI elements at all.

Thesis 1:

Interaction with sole gestures is more intuitive than interactions with a widget respectively using some kind of UI elements.

2.4.2 What Impact Do Navigation Metaphors Have on Intuitiveness?

Which metaphor is more intuitive for exploring the 3D world of the SGD using a multi-touch-display? Is it either the metaphor *scene-in-hand* or *eyeball-in-hand* (Ware, et al., 1990) or does it not matter?

Thesis 2:

The *eyeball-in-hand* metaphor in the context of the SGD is more intuitive than the *scene-in-hand* metaphor.

2.4.3 Which Role Does Technology and Implementation Have on Intuitiveness and Learnability?

What factors impact the intuitiveness and learnability of 3D interactions on multi-touch-screens?

Thesis 3:

An accurate and reliable technology and an error-tolerant implementation are key aspects to intuitiveness and learnability.

2.5 Conclusions for the SGD Based on Literature and Current State-of-the-Art Solutions

Taking all available literature and approaches into account, we can make some assumptions for multi-touch navigations using a maximum of two touch-points. The following conclusions outlined below serve as general argumentation to decide for possible solutions:

Use Gesture-Based Solution Instead of Widget-Based

Gestures alone - without the usage of any widgets - can work well on multi-touch systems (Fu, et al., 2010) (Hinrichs, et al., 2011) (Jacucci, et al., 2010), even for users that never have interacted like this before. Enhancing gestures with widget such as the power-of-ten ladder can add additional advanced interaction (Fu, et al., 2010). However, the number of possible touch-points support additional gestures and DOF, hence support more natural gestures (Hinrichs, et al., 2011) (Hancock, et al., 2007) (Schöning, et al., 2009). Widgets that are not positioned by the users themselves, and therefore are displayed statically on the screen, might suffer from the lack of *interaction locality* (Fu, et al., 2010).

From a theoretical point of view Thesis 1 can be verified to a certain extent, as gesture-based interactions are generally accepted and positively perceived by novice users. Though using gesture-based versus widget-based interactions does not give a clear assertion on the degree of leverage on intuitiveness. However, it has to be taken into account that systems supporting more than two simultaneous touch-points seem to be more intuitive and give more freedom on gestures to be chosen from.

Combine both Metaphors for Interactions/Manipulations

The choice between the metaphors *scene-in-hand* and *eyeball-in-hand* depends on the tasks that need to be performed (Ware, et al., 1990) (Stoev, et al., 2002) (Fu, et al., 2010). Neither is perfect, but if both are combined, their advantages can support the user to perform his task in a natural, convenient and intuitive way.

Thesis 2 from a theoretical point of view can be falsified with regard to effectiveness, efficiency and users' expectation, as both metaphors are needed depending on the tasks to be performed. The large-scale 3D astrophysical simulator as well as the Google Earth iPhone app show very nicely how both metaphors can be used in parallel.

It may be assumed that the *scene-in-hand* metaphor is preferred for large scale manipulations and movements, whereas *eyeball-in-hand* is preferred for small scale movements and maneuvering.

Hardware and Implementation Is Key to Intuitiveness and Learnability

The available literature does not give any clues on how accuracy and reliability of HW impacts intuitiveness and learnability as such, though there are certain theories on implementations that affect controllability and expectations. The freedom of control (Nurminen, et al., 2008), interaction locality (Fu, et al., 2010) as well as the implementation of metaphors such as *scene-in-hand* and *eyeball-in-hand* (Ware, et al., 1990) have a great impact on how interaction is perceived. Another HW-related fact is the amount of DOF supported by an input device, which makes mapping of gestures more flexible and therefore allows a higher degree of natural navigating and interacting (Hancock, et al., 2007).

As accuracy and reliability of HW is not specially mentioned in theory these characteristics are taken as “*conditio sine qua non*” for HW components.

Thesis 3 can neither be verified nor falsified as there are no assertions on how HW and implementation aspects affect intuitiveness or learnability of interactions. However, it may be assumed to be a key condition that influences intuitiveness or learnability.

3 Evaluation of Initial Solution and Improvements

3.1 Approach and Methodology

3.1.1 Requirements Analysis

The Smart Grid Demonstrator was developed as a research project with only vague visions of the founders in terms of what it should do and by whom it would be used. There was no written definition of the potential users and no real tasks or scenarios were defined. Not even a business case existed that could have helped the project team to take the first thoughts. Some initial ideas about what the SGD should do were present among marketing and the software developers. These ideas were only communicated verbally. Since a system can only be improved in terms of usability if users and their needs are clearly defined, it was obvious to the project team to put effort figuring out who the targeted users could be and what their tasks in which context could look like. Given this, missing facts would have to be defined by the project team. On the other hand, a full requirements engineering process would not be feasible, because the SGD is not a product as such. Hence, no existing users with known tasks could have been inquired. Therefore the requirements analysis was quite straight-forward, as it is explained below.

Conducting Interviews

The project team initially interviewed the founder and developer of the SGD. He was especially asked about the potential users, their tasks and the system in context with its environment. Two additional interviews were held; one with the communication responsible of ABB CRC and the other with the marketing responsible of the smart grid technology at ABB. Together with his superior the latter also founded the SGD project. Their idea was to have a test-setup to demonstrate the smart grid topics to interested customers. This test-setup should then be visualized on a touch-screen with an attractive 3D navigated user interface.

The first two interviews were guided. While one interviewer asked predefined questions to the interviewee the other team member wrote down the answers in catchwords. This interview technique allowed to ask additional questions in order to extend certain topics or for clarifying answers. The interviews were recorded electronically in order to have a backup for post-processing. A third interview was a discussion between one team member and the interviewee.

Analyzing Data from the Interviews

After the relevant answers of the interviews were captured, its contents were analyzed. Goodwin (2009) suggests analyzing interview data case by case in a first step, followed by a cross-case analysis. This process can be done either by deductive

reasoning (starting with existing general principle and comparing the data with it) or by inductive reasoning (trying to derive general principles from specific data). In order to gain thorough insight into the data, the material was reduced and organized. This was achieved by categorizing the answers of the respondents. According to Goodwin (2009), this process is both deductive and inductive.

In practice we followed the above-described approach. First we checked the interview data for clues about the user skills, goals and demography (deductive). Then we defined further categories that could be subordinated to the first ones defined (inductive). The results were fed into a spreadsheet, where the answers could be sorted by the categories.

Modeling Personas

“For design, the richest form of cross-case analysis results in personas” (Goodwin, 2009 S. 215). We modeled personas not only due to this, but also to gain a common understanding among the project team. A spreadsheet was filled out with definitions for users, which were mentioned by the interviewees. Then these definitions were enriched with statements from participants of the usability evaluation 1 with topics such as expectations, wishes, dislikes and fears. After having gathered all characteristics of potential users, it was a straightforward task to define the specific characteristics for the primary, secondary and non-personas. For this the spreadsheet was used as a morphologic box. A morphologic box, founded by Zwicky (1989), is a creativity technique that follows a systematic heuristic approach. It helps to find different solutions out of attributes with a number of characteristics. With the help of this technique all characteristics that possibly belong to a specific persona were colored and therefore grouped together. *Figure 3-1* below shows a part of the “*Requirements Analysis - Characteristics of Persona (Morphological Box)*” that can be found as a whole in the *Addendum*.

Category	Attributes	Characteristics		
Demography	gender	female	male	
	age	< 16	16 - 65	> 65
	profession	sales people [mn, sa]	researcher [mn]	energy expert [mn]
	user type	active user [mn]	casual user [mn]	non user (Families, Technorama visitors, children) [mn]
	user role	visitor [mn]	professional [mn]	
User skills	frequency of usage	regularly [ul]	occasionally [ul]	seldom [ul, mn]
	familiar with touchscreens	yes [ul]	no [ul]	
	Software skills	non [mn]	professional (8) [ul]	
User goals	aim	curiousness [mn]	exploring SGD [mn]	learning smart grid [mn]
	task	give demonstration [mn]	exploration [mn]	get demonstration [mn]
	fields of interests	smart grid [mn]	energy production, distribution, consumption	facility automation [mn]

Figure 3-1 Creating personas with aid of a morphological box

Only provisional personas were created because they were constructed from interviews of stakeholders and not from real users. Provisional personas are described in chapter 3.4 and the whole text on “*Requirements Analysis - Provisional Personas*” is also available in the *Addendum*.

3.1.2 Evaluating Initial Implementation

The evaluation of the initial implementation targeted to find major usability issues of the SGD. In addition to that it served to collect further user expectations in order to extend the basic needs that were defined, the stakeholder interviews. Furthermore findings of this first evaluation would build the base of proposed design improvements.

Expert Review

Before planning the first usability evaluation, the project team investigated the SGD by means of an expert review. In an expert review, an experienced design or usability professional steps through the product or design looking for likely problems and evaluates their severity (Goodwin, 2009 S. 651). According to Goodwin, expert reviews are generally quick and inexpensive. Even though we do not see ourselves as long experienced usability professionals, we took over the role of the usability expert. This approach gave us first insights of major problems and helped us to choose the appropriate evaluation methods.

Usability Evaluation 1

The usability evaluation 1 was conducted with nine participants. They had to complete six tasks in two test runs.

The participants for usability evaluation 1 were recruited mostly from ABB CRC staff because the evaluation was carried out with the SGD stationed in the lobby of the CRC. Most of the participants had never used the SGD before. However, the software developer of the SGD was also asked to participate in the usability test, but this data was not evaluated.

The usability test consisted of two test runs for each participant. In the first run, the participants had to explore the SGD without getting instructions. Target of the first run was to find out how intuitive the navigation was. Before starting the second run, the participants were given instructions on how the navigation was thought to be used and what functions the widget provided. The participants had to go through exactly the same tasks as in the first run. The second run should indicate how learnable the system was. Both runs took about twenty minutes in total.

The usability test started with a short introduction, where the procedure and the purpose of the test were explained. The participants had to carry out six tasks where one particular function was tested in every task. The first tasks were fairly easy such as, "Please move to the right and left to see other parts of the buildings". With each consequent task the complexity increased. However, the participants were not just told to execute a zoom- or a pan-function. An overview of the verbally given instructions can be found as "*Usability Evaluation 1 - Test Scenario*" in the *Addendum*. The first three runs of the usability tests were thought to be used as test runs to check if the given tasks were meaningful and if the setup as illustrated in *Figure 3-2* had to be changed. But the tasks and setup seemed to work well and it was decided not to change anything. This decision also had the advantage that these three test runs could also be used for evaluation and analysis.



Figure 3-2 Setup of the usability evaluation 1

Flashback Express (a screen-capturing software) recorded the actions of the participants during the usability test. Flashback Express is freeware and had been evaluated in advance among several others. Not only could it record the frames of the screen, but it also allowed recording the video and audio using an external camera and microphone. As a backup, an independent video camera was installed as seen in *Figure 3-2*. This entire setup was tested and adjusted some days before conducting the usability evaluation 1.

One team member lead through the usability test while another member stood a bit aside to observe and take notes. It was agreed that the observer could intervene with questions if appropriate. Although it was planned to post-analyze the entire video, notes were taken for possible questions for the following interview.

Following the usability test an interview was conducted. The participants were asked about their general impressions, their expectations, and if they could think of playing with and exploring the SGD for a longer time. One team member guided through the interview and another member took notes while an electronic device recorded the whole interview as backup. For reference see the “*Usability Evaluation 1 - Interview Guideline*” in the *Addendum*.

Finally the participants were asked to fill in the ISO standard questionnaire. This questionnaire was particularly designed to inquire the ISO standard criteria for software applications. Even though some questions were not applicable to the SGD, the participants were asked to answer the questions with best effort, leaving out questions that could not be answered.

Analysis

The videos of the screen capture software and the audio recordings of the interviews were first analyzed case by case. While watching the videos, remarkable usability issues were noted, tagged with timestamp and later typed into a spreadsheet in order to have a condensed protocol (an example can be found as “*Usability Evaluation 1- Protocol Example*” in the *Addendum*). In parallel to that, the interviews were analyzed. In order to deal with the data, these were then consolidated and transformed into prose. This process was a bit different from the requirement analysis. For every participant a consolidation sheet was created containing both texts from the interview and video analysis. Additionally the most significant issues observed from or mentioned by the individuals were written down as conclusions. An example of this can be found as “*Usability Evaluation 1 - Consolidation Sheet Example*” in the *Addendum*.

Success Rate

The *cross-case* analysis was done in a workshop following the usability evaluation 1 documentation. The consolidated data and the protocols of every case, as described above, were checked for remarkable issues. This means that the data of the video analysis was inspected for usability issues, functions that worked well and such that did not. Also gestures were noted that had been tried out but were not supported by the system. These findings were written onto sticky notes. After having pasted them randomly to the wall, the project team tried to group them together in order to build clusters. An impression of this process is shown in *Figure 3-3*.



Figure 3-3 Clustering of the usability evaluation 1 findings

Two affinity diagrams represented the results of this procedure. One reflected the test run before and the other the test run after instructions. Pictures of the affinity diagrams were taken for post-processing. Every sticky note was given a unique identification (ID) on these pictures. The notes were written on a spreadsheet including references like case and test numbers, categories as well as their ID (see “*Usability Evaluation 1 - Issues*” in the *Addendum*). This helped tracing the data throughout the whole analysis process. Finally the occurrences of the same issues were counted.

As mentioned earlier, the project team wanted to identify how easy the functions or gestures could be explored and how well they could be learned after giving instructions. In order to analyze this, the project team processed the data as follows: Each function was analyzed for each individual participant. The result, whether it was a success or fail, was transferred to a separate spreadsheet. Then for each function, the total number of successfully performed functions before the instruction was calculated. The same calculation was done after the instruction. On the one hand, each function could be compared regarding its intuitiveness. On the other hand, every successfully performed function after the instruction was marked, if it was unsuccessfully performed before giving the instruction. With this kind of analysis it could be concluded if a certain function was carried out successfully more often or not. This may give an indication for the learnability of certain function. The number of times a function could be learned by an individual can be seen from the yellow marked cells in the “*Usability Evaluation 1 - Interaction Success Rate*” document in the *Addendum*.

In a subsequent workshop the focus was on the user expectations. In order to figure out what users expected, the interview data as well as the consolidation of the test results were analyzed. The project team took a deeper look at what wishes, expectations, and ideas participants mentioned during the tests and interviews. Similar to the first workshop, findings were written onto sticky notes and then clustered to an affinity diagram. The results of the affinity diagrams were documented on pictures and again transferred to a spreadsheet (see “*Usability Evaluation 1 - User Expectations*” in the *Addendum*).

Both the usability issues and the user expectations were then prioritized. Issues that were out of scope were marked as secondary priority and were filtered out for further processing.

3.1.3 Development of Solutions and Design Process

First ideas in the early design process were developed in a workshop, for which Google Earth was examined to see how many degrees of freedom were implemented and how Google deals with the different approaches in normal and in ground view. Some ideas to work around the issue of sudden jumping and disappearing of objects with SGD were discussed. This led to some sketches on the black board that were photographed afterwards. Based on these discussions three design proposals were created.

On a further workshop the dataflow process was discussed in order to gain a common view of the upcoming steps. The challenge was to deal with a huge amount of data. These data had been analyzed in the meantime, but had to be transformed into clearly written design proposals so that a software engineer could understand and implement them. In parallel to this, usability goals according to Quesenbery (2004) were defined for the primary and secondary persona. This should not only help focusing the view during the design process but also ease the development activity of the appropriate solutions. All usability issues and user expectations were then addressed to the three design proposals created earlier.

Because of the similarity of the first two design proposals, their major points were combined into one, resulting in proposal A and B (refer to chapters 3.6.3 and 3.6.4). A new document was created in which every prioritized usability issue and user expectation was merged together with the two main solutions. This process was done in several iterations where every team member worked individually. Finally this document clearly illustrated what should be changed, why it is proposed and what theory it is based on. This was intended as an instruction for the software engineer.

Implementation Process

The final document “Solution Proposals” was sent to the software engineer. During the following implementation process the project team and the software engineer were in close contact in order to clarify ambiguity and react on design changes. The software changes were implemented step by step. Given this, the project team had the chance to test parts of already implemented solutions and to give feedback to the software engineer. Finally the end version of the software was examined by conducting a hallway test. This also worked as a pre-run and gave valuable inputs for the second usability test. As proposed by the project team two software versions were provided. *Figure 3-4* illustrates the hallway test on a tablet PC.



Figure 3-4 Hallway testing with tablet PC

3.1.4 Evaluating Proposed Solutions

The purpose of this evaluation was to carry out a summative usability test of the new software solutions in an almost realistic situation. A summative usability test evaluates an interactive high fidelity prototype and measures predefined usability goals to have a comparison with other products (Cooper, et al., 2007). No or negligible interaction should take place between the participants and the test supervisor. This reflects a typical situation, where a novice user is exploring the SGD while having about ten minutes spare time in the lobby of ABB CRC. Besides offering qualitative, conclusions the tests should also give quantifiable results in order to compare the two solution proposals, indicate improvements against the first prototype and last but not least auditing the usability goals for the primary persona.

Usability Evaluation 2

The second usability evaluation was conducted with eleven participants. They had to complete four tasks in two test runs.

The usability evaluation 2 was not conducted with the original SGD at CRC ABB because there were some concerns about system performance. Therefore the tests were conducted at the ABB building in Turgi. A 21" multi-touch-screen, which has the same infrared sensors as the screen at the CRC for gesture detecting, was used for these tests. Besides that, the setup was similar to the usability evaluation 1. The same screen capture software with an external microphone and video camera as well as an additional stand-alone video camera was set up. Eleven participants were invited to the tests; ten showed up. During the spare hour the project team took the chance to conduct a third software version as *hallway tests* with two of the nearby staff. The third software version used different gesture directions for rotation (yaw) and pan.

The “*Usability Evaluation 2 - Test Scenario*”, which can be found in the *Addendum*, consisted of four different tasks checking all improved functions. After a short briefing, printouts of the scenarios were given to the participants that included short descriptions of the tasks and illustrations of the targeted view. The participants were asked to perform the tasks while speaking what they thought (think aloud). When participants got lost and did not know further they got hints in order to proceed with the tasks; in worst case the gestures were shown. Since there were two software versions to be tested, the same four tasks were used for version A and B.

This test design had its advantages and disadvantages. In a typical *within-subjects design*, like the one used here, every participant was subjected to every single test version (Shuttleworth, 2009). The advantage of this was that fewer participants had to be invited. One of the disadvantages was the so-called *carry-over effect*, which means that participants could have learned how and got familiar with general characteristics of the SGD during the first test run. This could adversely influence the second test run. The *carry-over effect* could be eliminated with a *between-subjects design*, where a group of participants go through only one test version and another group runs through a second test version. The negative side of this would be that more participants were needed. Because of practical reasons (fewer participants and less time) we decided to do a *within-subjects design* and reduced the *carry-over effects* by altering the test sequence (A-B, B-A, and so on).

Participants Interview

After the usability test, the participants were interviewed. The purpose of conducting interviews was to get some statements on intuitiveness of the solutions, opinion about the gestures used, preferences of solution, and to find out if users noticed any difference between the two metaphors *scene-in-hand* and *eyeball-in-hand*. In contrary to the semi-structured interviews in the usability evaluation 1 a structured interview was used for the usability evaluation 2, where the interviewees were asked precise questions. The intention of doing so was to have comparable answers. One team member guided through the interview and another member took notes while an electronic device recorded the whole interview as backup. For reference see “*Usability Evaluation 2 - Interview Guideline*” in the *Addendum*.

Questionnaire

As in the usability evaluation 1 the participants were asked to fill in the ISO standard questionnaire, which was printed on paper. Since there were two software versions to assess, the participants had to rate only the last version that was used in the test run. With this method, the two software versions could be compared with each other, because half of the participants rated version A and the others version B.

Analysis

Before starting the analysis of the usability evaluation 2, criteria were defined on how the videos had to be assessed and which issues had to be looked for. It was of particular interest to determine if problems seen in the usability evaluation 1 were solved by the changes of the design proposals. In order to analyze the improvements a checklist was created to check against the videos. Refer also to the “*Usability Evaluation 2 - Evaluation*” document in the *Addendum*, where the blue colored questions represented the criteria to be analyzed.

The videos were examined again in order to determine how well each function could be carried out. Each function was rated from very easy (1) to unable to perform (5). These numbers were stored in a table to compare the intuitiveness of each function. Furthermore the time to complete each run was determined.

The interviews were analyzed in two steps. A spreadsheet was initially created with columns such as question number, participant number, and test sequence. Each team member filled in his notes taken during the interviews and checked them against the recorded interviews where necessary. After the spreadsheet was completed with all data it was examined by a structured content analysis in a similar fashion as the requirements analysis using main categories which had already been defined during the interview guideline development. With a *cross-case analysis* similar answers were

grouped together and rearranged into subcategories. In contrary to the requirements analysis described earlier the goal was not to model personas but to create conclusions for each main category. In addition to that, the influence of the test has been analyzed in order to evaluate possible systematic bias. This was relating to whether participants rated the first test run better than the second or vice versa.

The results from the *ISO standard questionnaires* were gathered in a spreadsheet in order to figure out the mean value and standard deviation of all usability criteria and overall values. Three different diagrams as seen in *Figure 3-28* were created to illustrate the results from the usability evaluation 1 as well as the results of versions A and B from the usability test 2. (See *Addendum* for “*Rating of Initial Solution, Solution A and B According to ISO Questionnaire*”)

3.2 Description of the Initial Solution

The SGD UI prototype as described by Martin Naef and Ettore Ferranti (Naef, et al., 2011) is using a multi-touch navigation interface with a three-dimensional data model. It extends 2D interaction gestures to work with a 3D *scene-in-hand* metaphor using a widget to select a manipulation axes and to navigate. A nested, semi-transparent display of the data hierarchy requires careful selection of the manipulation pivot. A hit-testing scheme is applied to select the most likely object within the hierarchy.

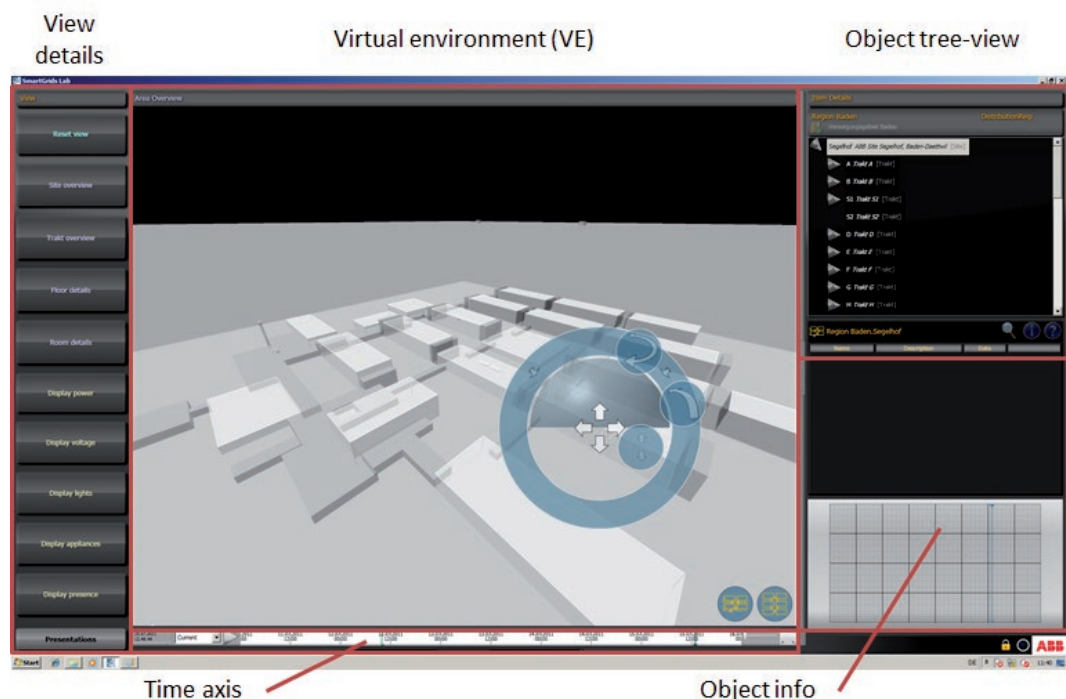


Figure 3-5 SGD UI with the five viewports

The UI screen is segmented into five viewports. The virtual environment (VE) view is the main area, where the widget navigation takes place. The view details buttons on the left navigation bar are used to present object status information in the VE view. An object tree-view and object info area on the right display detailed data about a selected object. The time axis at the bottom serves as navigation to view historical data.

The navigation mode is based on a look-at point (center of view) that can be placed anywhere in the VE. With the help of the navigation widget as shown in *Figure 3-6*, the user can navigate in the VE.

The widget is shown and becomes active, when the screen is being touched. The system then sets the pivot, defined by the intersection of the virtual ray and the selected object (done by the hit-testing scheme).

The widget then can be used to navigate in the VE by using the controls:

- A) Pan (pans)
- B) Elevation (heave_s)
- C) Zoom (grab)
- D) Pitch (pitch_s)
- E) Rotate (yaw_s)
- F) Sphere rotation (combined yaw_s and pitch_s)

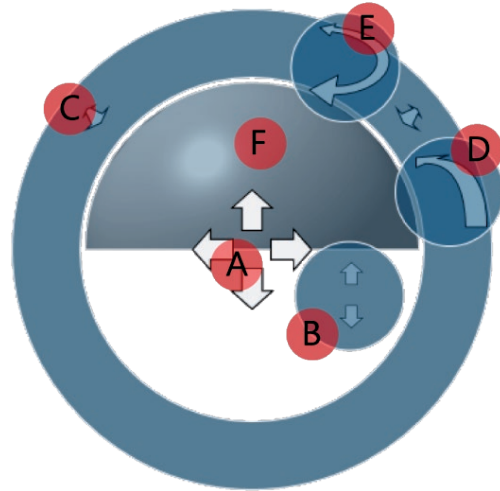


Figure 3-6 Navigation widget of the initial solution

The user can freely navigate in the 3D space, without any limitations of buildings or surface, thus without collision detection.

The application was developed using C# and the Microsoft .NET 4 framework. All 2D user interface elements including the navigation widget were implemented using Windows Presentation Foundation. 3D rendering was implemented using DirectX 10.

The software runs on a range of devices to accommodate for the presentation scenarios. Common to all of them is the requirement for Microsoft Windows 7 and support for DirectX 10 graphics. All screens must support the detection of two touch-points.

3.3 PC and Display Hardware

The largest presentation device is a 42" multi-touch-screen with optical (infrared) touch detection. It is the appointed display for public use at ABB CRC and therefore used for the first evaluation. The second evaluation was also planned to be done with the original hardware, but had to be skipped because of significant system deficiencies.

A desktop PC with a medium sized 21" multi-touch-screen and full HD resolution with optical (infrared) touch detection was used for the second evaluation instead of the 42" screen.

The smallest configuration is a tablet PC with 11" 1280x800 pixels capacitive touch-screen. It was mainly used for development and *hallway tests*.

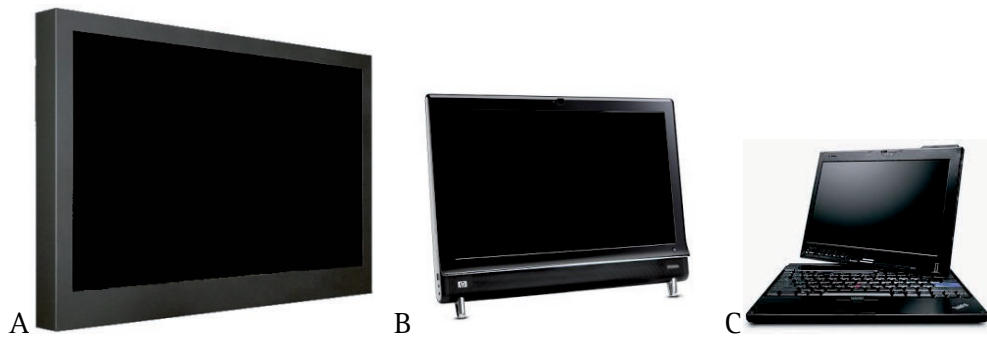


Figure 3-7 Touch-screens used: A) 42" large screen, B) 21" desktop PC, C) 11" tablet PC

3.4 Provisional Personas

As described in chapter 3.1.1 provisional personas were derived from the requirements analysis and the first evaluation. The complete definition of “*Requirements Analysis - Provisional Personas*” can be found in the *Addendum* and the main characteristics are listed below.

Provisional primary persona is a user that has never used SGD before but wants to explore the possibilities of the smart grid technology. He gets attracted by the SGD in the lobby of the ABB CRC and starts playing while waiting for his appointment.

Provisional secondary persona is a smart grid professional, working as a sales person within ABB. He regularly gives presentations to customers on the SGD. Therefore he wants to effectively navigate with a fast and precisely working system.

The Provisional Non Persona is a software engineer who works in the development team of the smart grid project. He likes to get statistical data of energy flows in transmission lines in order to visualize them as trend charts.

3.5 Results from the First Evaluation with Initial Solution

The usability evaluation 1 was set up in three parts; a usability test, an interview and a questionnaire according to ISO standard 9241-110.

Based on the observations made in the usability test, all usability issues were listed, categorized and prioritized according to their severity. For each item a proposed solution was compiled and consolidated in two different solution proposals described in chapter 3.6.

The interviews were compiled in an expectation list similar to the usability issues.

Furthermore an evaluation based on the observations made in the usability evaluation 1 was carried out to assess how successful the widget functions were explored and operated.

3.5.1 Main Usability Issues Identified

The major usability issues observed in the usability evaluation 1 are listed in *Table 3-1*. Each usability issue is identified with a unique ID (Uxx) for further reference. A detailed list of “*Usability Evaluation 1 - Issues*” is available in the *Addendum*.

Table 3-1 *High priority usability issues*

Problem	ID	Usability Category	Affected Component
<i>Widget jumped</i>	U09	System Failure	Widget
<i>Widget not appearing</i>	U11	System Failure	Widget
<i>Double-tap does not respond</i>	U13	System Failure	System
<i>Model jump</i>	U30	Unexpected behavior	System
<i>Zoom jump</i>	U18	Unexpected behavior	System
<i>Difficulties with learning gestures</i>	U20	Unexpected behavior	Widget Control
<i>Irritating info pop-up</i>	U19	Unexpected behavior	Pop-up
<i>Info pop-up overlaps widget</i>	U31	Unexpected behavior	Pop-up
<i>Wrong control chosen</i>	U01	Affordance	Widget Control
<i>Does not understand reset icons</i>	U02	Affordance	Reset Button
<i>Elevation in wrong direction</i>	U34	Mental Model	Model
<i>Mental model; first person view</i>	U08	Mental Model	Model
<i>Two-finger gestures expected</i>	U25	Expectations	Widget Control
<i>It reacts too slow</i>	U28	Expectations	System

The observed issues were evaluated and investigated further to discover the root causes. In the following chapters the cases are described in detail.

System Failures and Deficiencies

Relating usability issues: U09, U11, U13, U18, and U30

One of the major usability issues identified was that five out of eight participants experienced “jumps” of the widget or the 3D model while zooming. These jumps confused the participants, or even prevented them to learn particular gestures.

This problem could be related to the touch-screen technology in use. One reason for this could be related to the finger positions and their movements that were detected by infrared sensors. A false signal might be detected when other fingers than the one touching the screen comes near the surface and interferes with the infrared beams. Other reasons could be insufficient accuracy and precision of the touch-screen sensor as well as a probable lack of software error tolerance.

Pivot and Gain Implementation

Relating usability issues: U08, U18, and U30

Half of the participants faced serious troubles while zooming (grab) and panning (pan_s) but also while rotating (yaw_s). The 3D model moved in a way that participants were confused completely. In some cases the participants felt like losing control and they had to reset the view and start from scratch. The following situations could be observed.

Panning back and forth (surge_s) while crossing the horizon:

If the user started panning down (surge_s) setting his finger above the horizon as illustrated in *Figure 3-8 (a)* below, the model just flew outside the visible area. The same happened in the other direction, if the user started panning up (surge_s) and setting his finger somewhere on the ground of the model and moving it beyond the horizon (b). If the model was pitched (pitch_s) to a certain amount, the movement of the finger which is transformed to the 3D model got accelerated to an extreme factor. This was in contrast to the participants' mental model and therefore led to loss of orientation.

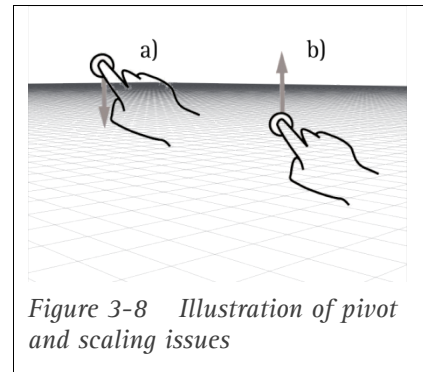


Figure 3-8 Illustration of pivot and scaling issues

Panning left or right (sway_s):

Panning left or right (sway_s) was no problem as long as the participant did not set the pivot to a far distance (e.g. near to the horizon). If setting the pivot to a far distance and the participant tried to pan left or right, the foreground of the model moved extremely fast. Again this was because the point of control was in a far distance to the viewpoint. This caused extreme scaling factors of the finger movement transformed to the model.

Zooming (grab):

If the participant tried to zoom-in (grab) a distant object that was located close to the horizon, hence set the pivot to a far distance, the speed of the zoom was again unexpectedly fast. This caused some of the participants to lose control and orientation.

All of the above described situations also occurred when the participant thought to touch an object in the foreground but in fact reached a point somewhere in the far distance of the model. The set pivot, which was determined by the software, was sometimes not transparent to the participant. Due to insufficient accuracy of the used touch-screen sensor, the troubles which the participants experienced were even amplified.

Widget Behavior and Affordance

Relating usability issues: U01, U02, U20, U25, and U28

The usability test also showed problems that can be seen related to the widget since at least three participants had difficulties in learning gestures to operate it. Even after getting instructions in the second run of the tests, they still had problems to choose the right function. Besides, six out of eight participants used the pinch gesture in a first attempt to zoom (grab). In general these six expected to use two-finger gestures (e.g. iPhone) to interact with the 3D model.

In the first part of the usability test two participants moved their finger right after touching the screen while trying to pan or zoom. Even though the widget appeared after a short delay, two participants ignored it completely initially. Therefore it can be assumed that participants expected to pan immediately after touching the screen, not waiting for the widget to get active first.

Other issues were seen with four of the eight participants that chose the wrong widget control several times. Also two participants did not understand some of the widget control icons or the reset button on the lower right corner of the VE viewport.

Irritating and Disturbing Info Pop-ups

Relating usability issues: U19 and U31

Double-tapping on an object displays detailed information about it (info pop-ups). The tests revealed that this did not work as expected or the participants had troubles double-tapping on a specific object. In more than one case info pop-ups appeared unexpectedly for the participants and they could not see the relation to an object. In five cases these pop-ups overlapped the widget and hindered the participant to operate the widget.

Users' Mental Model

Relating usability issues: U08 and U34

As already described in above issues, some participants had difficulties understanding where the pivot was set by the system and its resulting gain and acceleration factors for gesture movements. Three participants also expected the model movement for elevation to go into opposite direction.

In addition, we found out that participants were not aware that behaviors were different depending on where they set the point of control (pivot).

3.5.2 Main User Expectations Identified

The main expectations expressed by the participants during the interviews are listed in *Table 3-2*. Each expectation item is identified with a unique ID (Exx) for further reference. A complete list (*Usability Evaluation 1 - User Expectations*) is available in the *Addendum*.

Table 3-2 High priority user expectations

Expectation	ID	Usability Category	Affected Component
<i>Faster reaction of system & widget</i>	E17	Reaction	System
<i>No delay for the widget to display</i>	E18	Reaction	Widget
<i>Use uniform pattern for interacting</i>	E10	Interaction	Gestures - non Widget Interaction
<i>Omit the widget and just use gestures</i>	E14	Interaction	Gestures - non Widget Interaction
<i>Widget must be intuitive to use (how to get it and how to keep it)</i>	E01	Interaction	Widget
<i>If the widget is under my finger, it should stay there</i>	E06	Interaction	Widget
<i>Key instructions</i>	E37	Guidance Information	Help Functions
<i>Help instructions for the functions</i>	E40	Guidance Information	Help Functions
<i>Descriptions on the buildings themselves</i>	E29	Guidance Orientation	Model
<i>Landmarks to orientate</i>	E32	Guidance Orientation	Model
<i>Colors to distinguish different things</i>	E33	Guidance Orientation	Model

The listed items of the interviews are grouped and formulated in detail below.

System Delays

Relating user expectations: E17 and E18

Five out of eight participants complained about the slow reaction of the system. There are several reasons for that.

1. Users may feel that the system is slow because of the programmed delay time for calling up the widget.
2. The model seems to move in a delayed way and follow behind the widget when manipulated. It gives the impression as if there was a transparent rubber band that links the widget with the model. However, one participant mentioned that it is great that the model slowly comes to a halt when letting go of the widget like it had some kind of mass.

Visual Design and Guidance

Relating user expectations: E29, E32 and E33

Four participants expected a more realistic visual design of objects that would help to orientate themselves better.

Three participants expected to have some descriptions or labels on the buildings to help orientating in the model, which may also omit the need for info pop-ups. Two participants missed some landmarks on the model.

User Help

Relating user expectations: E37 and E40

Five participants stated in the interviews that they wished to have some key-instructions, help information, and information about the functions of the widget.

One participant did not understand the view details buttons on the left navigation bar.

Widget Affordance and Gestures

Relating user expectations: E01, E06, E10, and E14

Five participants expressed their expectations and required improvements for the widget and its operation. The widget should generally be more intuitive to use in the sense of how to call it, keep it and operate it. It should use a uniform pattern for interaction (the point here was that pan uses a one-finger gesture, whereas all other functions require two-finger gestures).

Three of eight participants explicitly expected to omit the widget and to interact with “gestures-only”. Statements like “it should react/behave like an iPhone”, “omit the widget and just use gestures” or “widget does not help much” emphasized this. This expectation could also be observed in the usability test, where e.g. more than half of the participants used a pinch-gesture for zoom (grab) and some participants tried rotation (yaw_s) and pan (surge_s) with gestures-only.

3.5.3 Interaction Success Rate

The rate between successful exploration and operation of the widget functions before and after instruction gave an indication about the intuitiveness of the widget (functions) as well as how successfully these functions could be learned. The following table shows the results about eight observed participants. All details can be seen in “*Usability Evaluation 1 - Interaction Success Rate*” in the *Addendum*.

Table 3-3 Interaction success rate

Widget function	Total successful Exploring	Total successful Learning	Sum of learned Functions	Sum of unlearned Functions
<i>Zoom (grab)</i>	4	6	3	1
<i>Rotate (yaw_s)</i>	5	6	2	1
<i>Pan (pan_s)</i>	6	6	1	1
<i>Pitch (pitch_s)</i>	4	5	2	1
<i>Elevation (heave_s)</i>	2	3	2	1

The results show that functions like pan and rotate are more intuitive to operate, whereas elevation could only be explored by two participants. Generally the learnability was rather limited, even the most intuitive function pan could not be operated by two participants after the instruction. An interesting outcome was that for each widget function there was a test participant who unlearned a function or could not successfully repeat a function after getting the instruction. This may indicate that participants generally were overburdened with operating the widget.

3.6 Designing an Intuitive Solution for Novice Users

According to Quesenbery, design key aspects and general design guides were emphasized for a primary and a secondary persona. The solution proposals were then developed focusing on novice users – the primary persona.

3.6.1 Design Key Aspects

Considering the main usability issues and user expectations investigated in the first evaluation, two different solution proposals were developed in order to:

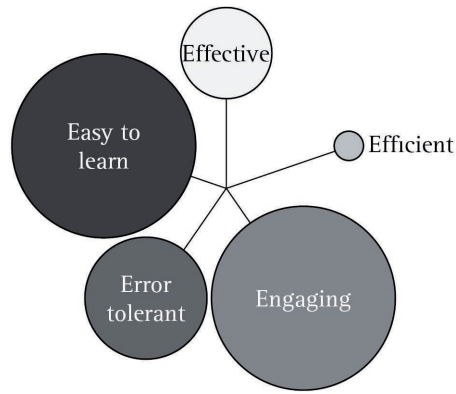
- Make system more robust with more error-tolerant interaction
- Improve system response time
- Find the navigation metaphor that is best fitting the user's mental model
- Leverage affordance to operate widget
- Improve scaling and acceleration factors
- Leverage usability and affordance of the pivot
- Improve user help and guidance

PC- and display-related issues are out of scope, due to missing time for further investigations, funding etc.

Design changes for the model are put on low priority due to high efforts and focusing on the 3D interaction, which should be addressed first.

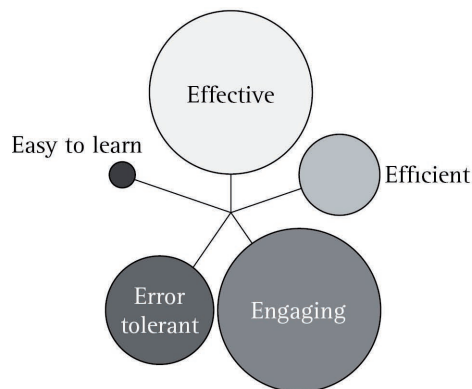
Environmental aspects like installation location or attraction measures to engage the user to use the display are not in focus.

The figures and table below show the design emphasis defined for novice users as well as for demonstrators.



Effective	15 %
Efficient	5 %
Engaging	30 %
Error tolerant	20 %
Easy to learn	30 %

Figure 3-9
Design emphasis for
novice user (primary
persona)



Effective	30 %
Efficient	15 %
Engaging	30 %
Error tolerant	20 %
Easy to learn	5 %

Figure 3-10
Design emphasis for
demonstrator
(secondary persona)

Table 3-4 Design emphasis for novice user (primary persona)

Dimension	Weight	User Needs
<i>Effective</i>	15 %	Achieve goals to learn about smart grid and get detailed information about objects.
<i>Efficient</i>	5 %	Infrequent use, efficiency not relevant as long as goals can be achieved in certain time. Depends also on attractiveness (engaging).
<i>Engaging</i>	30 %	Wants to explore goals which are developed during exploring. Wants to be inspired in no less than 10 minutes. Expects attractive 3D model.
<i>Error-tolerant</i>	20 %	Expects that system reacts as wanted, no loss of control. Wants easy and quick help when struggling.
<i>Easy to learn</i>	30 %	Just wants to play and does not want to invest time to learn how to interact. Expects intuitive and uniform gestures and easy orientation.

Table 3-5 *Design emphasis for demonstrator (secondary persona)*

Dimension	Weight	User Needs
<i>Effective</i>	30 %	Needs to achieve exactly what has to be presented, with accurate precision.
<i>Efficient</i>	15 %	Presentations need to be fluent, system has to react accordingly. Presentations may not be thwarted.
<i>Engaging</i>	30 %	The UI is <i>the</i> marketing instrument for the Smart Grid Demonstrator. Attractive 3D model expected.
<i>Error-tolerant</i>	20 %	No unexpected system reactions, no loss of control.
<i>Easy to learn</i>	5 %	Has low priority because of frequent usage. The use cases for presentations are usually already prepared.

3.6.2 General Proposals

The general proposals mainly relate to improvements of the 3D model and apply in conjunction with either solution proposal A or B.

Provide Key-Instructions and Help

A help screen should be offered by the system when clicking on an overall help button. A semi-transparent overlay would then cover the complete screen giving quick tips on how to use the system, its functionalities as well as gestures for navigation.

Context Information

In order to assist users, finding context information of a certain object, context menus could help. These could be activated by tapping on the specific icon on the object. To make it clear which object the context menu belongs to, the corresponding object could be highlighted.

Remove Delays and Rubber Band Effects

Programmed delays and rubber band effects should be reduced or removed completely. A direct feedback provides better control of the model to the user.

Provide Landmarks and Landscape

An easy solution leveraging the user's orientation would be to add the fountain in front of the entrance of the campus. The fountain is well known to everybody and prominently visible.

A small landscape provided on the edge of the VE viewport could help the user to see where he is located within the campus, especially when zoomed in far into the model.

Improve Visual Design

Use of different colors for objects or sensors would improve orientation. Designing active objects more realistic would help finding certain things easier.

3.6.3 Proposal A: *Scene-in-Hand* Metaphor with Widget Interaction

The described variant proposes a solution keeping the *scene-in-hand* metaphor with a modified and improved widget.

For this solution we propose to change the widget's behavior and its visual design including the rearrangement of the icons. The reason for changing the behavior such as for zoom, pitch, rotate, and elevation is to harmonize the gestures. It also allows easier manipulation. There is no torsion of the wrist for rotating and no spreading of the fingers far apart for zooming in. This solution also minimizes the display being touched accidentally by other fingers. Furthermore the different positioning of the controls and the increased distance between the controls and fingers might help to minimize the misinterpretation of taps especially with rotation gestures (resulting in widget jumps).

The figure below illustrates the functionality and layout of the widget as well as the interaction specific to the *scene-in-hand* metaphor. With this metaphor the pivot is not easy to determine within a 3D model. Therefore it is not always obvious for the system to know where in the three-dimensional space the user sets the point of control. This is one of the main causes of unexpected moving and jumping of the model and losing control of the model when panning and zooming. Although that problem is not solved with this solution, a redesign of the widget should solve many irritations the user faces when using the widget.

Optionally the pivot could always be set to the center of the model in order to always have a clearly defined point of operation.

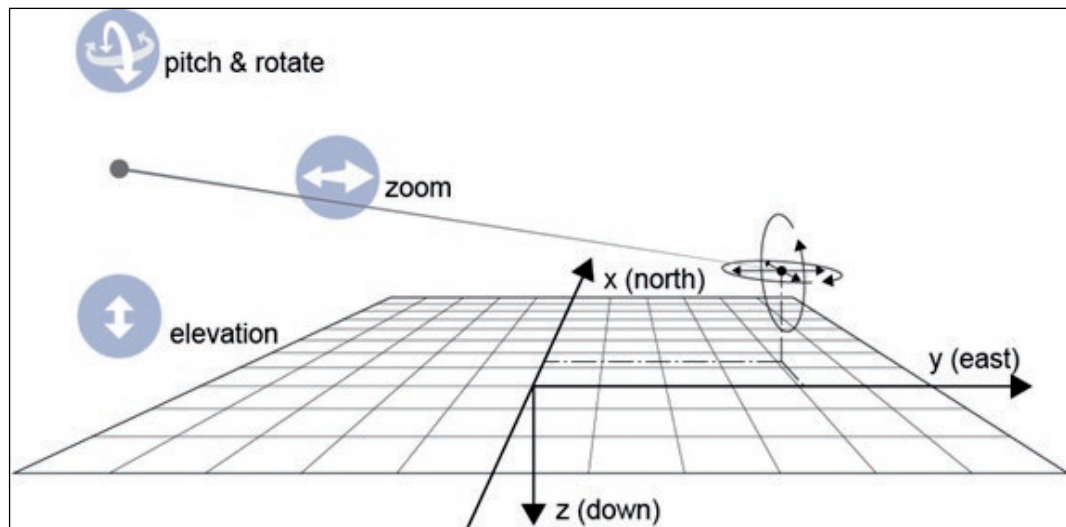


Figure 3-11 Improved widget with scene-in-hand metaphor

Redesign Widget

The widget is redesigned to address the problems occurred in the first evaluation.

The icons of the widget are more distinct and are farther away from each other. The gestures to operate the functions are easier to use: using linear horizontal or vertical finger movements only.

The delay for the widget to appear is removed in order to give the user direct feedback and affordance.

The support for panning parallel to elevation/zoom or pitch & rotate was removed in order to simplify operation and not overburden the user.

Pan:

The pan function is activated automatically and without delay, when the user touches the screen and moves his finger. There is no symbol used for this function. Swiping left/right and up/down pans (pan_s) the model into the respective direction. The other icons for pitch/rotate, zoom, and elevate are visible but very transparent.

Zoom:

Tapping the zoom control with a second finger activates the zoom (grab) function while the symbol changes to less transparency. Swiping to the right zooms into the model and swiping to the left zooms out of the model. The zoom function is released, when the user withdraws his fingers from the touch-screen.

As an option, the zoom function could be toggled on and off by tapping the zoom symbol. The user can then zoom by using just one finger. The function stays on until the user taps on the zoom symbol again.

Pitch and Rotation:

The pitch (pitch_s) and rotate (yaw_s) function is activated and used in the same way as the zoom control described above. Swiping to the left rotates the model clockwise and swiping to the right counter-clockwise. Swiping a full screen width rotates the model 360°.

Swiping down pitches the model towards the bird's-eye view and swiping up pitches the model towards the horizontal position. Swiping a full screen height pitches the model 90°.

Figure 3-12 shows an example on rotating the model using the combined pitch/rotate control. Note: this function works also with one finger.

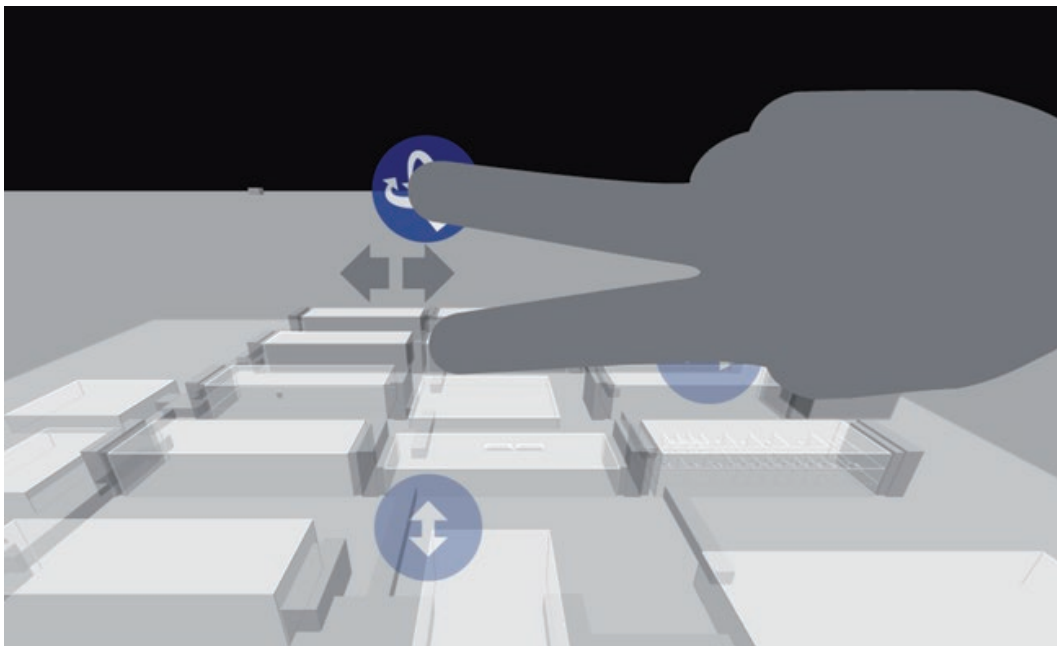


Figure 3-12 Example on rotating the model with improved widget

Elevation:

The elevation control (heave_s) is similar to the other controls. Swiping down moves the point of view to a higher altitude and swiping up brings the point of view towards the ground plane.

Limit Gains and Area of Action

The area where the movement of the finger is transformed proportionally to the 3D models projection should be limited. The point of control should be restricted to the area below the horizon. The following explanation shows how this area could be defined.

Let's assume we are looking from the bird's eye view perpendicular to the ground. We then draw an imaginary circle which is outside the visible area (refer to *Figure 3-13*).

Now we lower our point of view and pitch the 3D model the same time, so we get a perspective view of the model. At this point parts of the circle get visible as shown in *Figure 3-14*. We can see an elliptical line that represents the limiting circle described above.

We can pitch the model even more so we get a flatter view of the 3D model as shown in *Figure 3-15*. This is an extreme situation, where we have the biggest acceleration factor if e.g. panning towards the horizon. Hence we face the problems described in chapter 3.5.1.

As mentioned above, the proposed solution is to limit the acceleration. In other words below the red line (within the red circle) the movement of the user's finger is transformed proportionally. As the user moves his finger above the red line (outside the red circle), the movement speed does not accelerate further. The speed stays consistent all over the area above the red line.

Definition of limiting area and gain factors:

Creating the right formula for the limited area and gains seem to be a complex task. The diameter of the red circle has to be figured out iteratively. The goal is to give the user a natural feeling of the interaction and that the user gets the impression of having full control over the model navigation. Therefore this formula will be developed during the implementation phase and has to be tested by users.

On-the-Fly Help

Optionally, a short help message could be displayed on how the gestures work, when a control is activated. The message then disappears into the place where the help button (refer to chapter 3.6.2) is presented. These messages can of course be deactivated by the user.

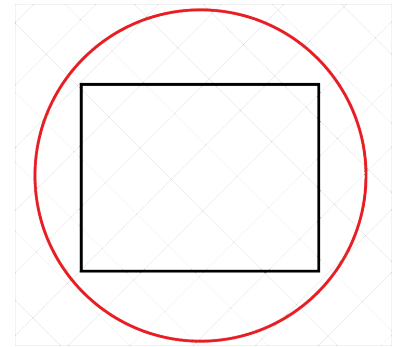


Figure 3-13 Bird's eye view to the 3D model with limiting (red) circle

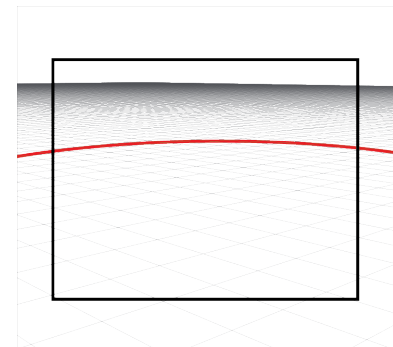


Figure 3-14 Perspective view to the 3D model with limiting (red) circle

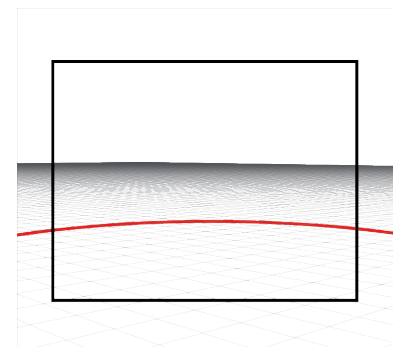


Figure 3-15 Almost horizontal view to the 3D model with limiting (red) circle

Place Info Pop-up behind the Widget

In order to prevent the widget being covered by the info pop-ups, they should be placed behind the widget or should not be displayed at all. Alternatively, labels could be displayed when going below a certain distance to the object.

Change of Touch-Screen Technology (out of Scope)

As already mentioned in chapter 3.6.1, PC- and display-related changes are out of scope. Nevertheless this point would be a key aspect in further improving the solution. The response behavior of the system could be improved, widget and model jumps drastically minimized, if a more precise touch-screen technology such as capacitive technology was used.

3.6.4 Proposal B: *Eyeball-in-Hand* Metaphor with Gestures-only Interaction

The described variant proposes a solution using an *eyeball-in-hand* metaphor with gesture(-only) interaction without the need for a widget.

The main difference between the two metaphors *scene-in-hand* and *eyeball-in-hand* is that there is no need to actually find a point within the 3D model, which is required to perform manipulations. Finding a point in the model is something which needs to be interpreted by some kind of algorithm as the system cannot exactly know where the user is actually pointing at. Additionally to this we found out that for many interactions the user was not aware that the behavior is different depending on where he sets the pivot. With the *eyeball-in-hand* metaphor this problem of finding the point of control (the pivot) does not exist, as it is always clear to the system at which point the manipulations takes place – the eyeball. Ware & Osborne (Ware, et al., 1990) mention that the *eyeball-in-hand* concept can confuse orientation and seems not to be the mental model of users navigating through a 3D model, at least in their setup. However, other references mention that good results had been found. Thus, given that the *scene-in-hand* concept is better for large scale traveling through vast environments and the current usage of the SGD is for a smaller scale model, the *eyeball-in-hand* concept seems to be a suitable solution for the SGD.

There are several possible advantages and disadvantages compared to the *scene-in-hand* concept:

- + The reduction from 6 to 5 DOF reduces complexity for the user to navigate
- + No loss of orientation due to sudden jumps of the model as it can happen with the *scene-in-hand* concept when panning, zooming, tilting and even rotating the model
- Panning up and down, when looking at the horizon will move the altitude (pane) of the eyeball. This is something not very often seen, but exists e.g. in *Cinema 4D*
- Rotating an object (yaw_s) is not possible, hence the user needs to rotate around it. If this is a requirement another DOF would be required to implement

The figure below gives an overview of the *eyeball-in-hand* metaphor with the five DOF, the view of the eyeball which can be moved in the VE.

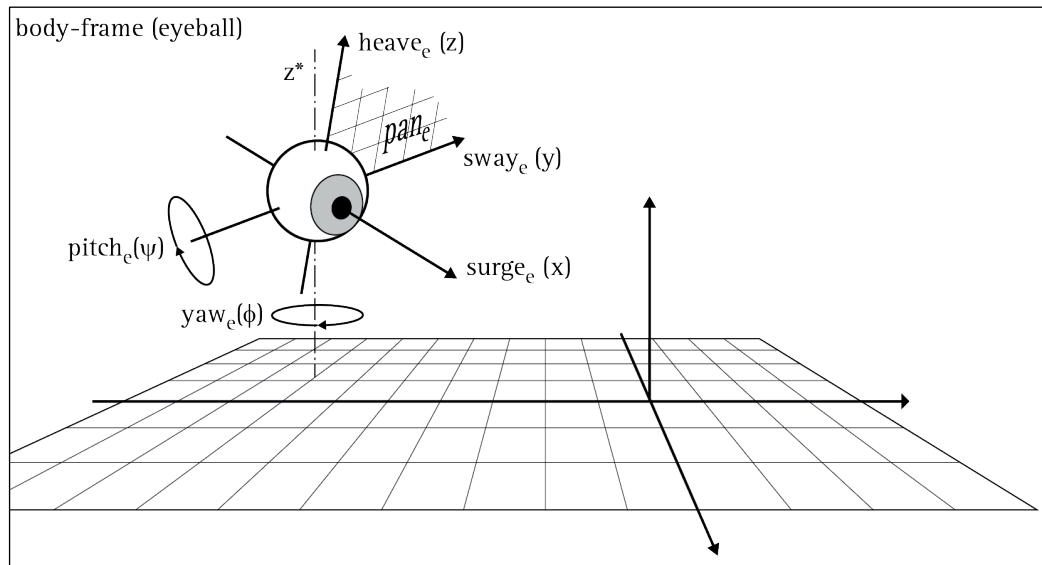


Figure 3-16 Principle of the eyeball-in-hand metaphor

Five Degrees of Freedom

The following DOF are used:

- [1] Yaw_e: z^* -axis rotation of the body-frame
- [2] Pitch_e: y -axis rotation of the body-frame
- [3] Surge_e: x -axis transition of the body-frame
- [4] Sway_e: y -axis transition of the body-frame
- [5] Heave_e: z -axis transition of the body-frame

Gestures

For rotations [1] and [2] a swipe gesture [A] with two fingers is used.

- Swiping left and right triggers a rotation around the z^* -axis (yaw_e)
 - Swipe left - eyeball turns right
 - Swipe right - eyeball turns left
- Swiping up and down rotates the view around the y -axis (pitch_e)
 - Swiping up - eyeball turns down
 - Swiping down - eyeball turns up

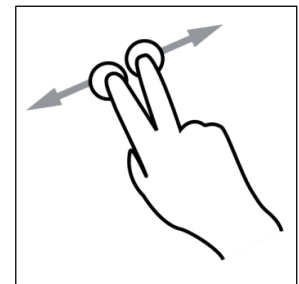


Figure 3-17 Two-finger swipe gestures

For panning [4] and [5] a swipe gesture [B] with one finger is used.

- Swiping left and right moves the viewpoint (eyeball) along the y -axis (sway)
 - Swiping left moves the eyeball to right
 - Swiping right moves the eyeball to left
- Swiping up and down moves the viewpoint (eyeball) along the z -axis (heave)
 - Swiping up moves eyeball down
 - Swiping down moves eyeball up

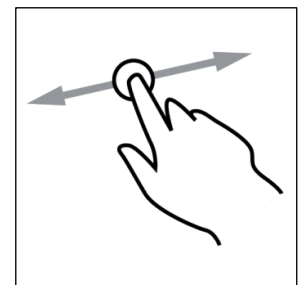


Figure 3-18 One-finger swipe gestures

The standardized one-finger swipe gesture p_w is defined as 100 mm, which is translated to the panning distance d_{pan} in the VE.

For zooming or heading [3] a pinch gesture [C] is used.

- Spreading the two fingers moves the eyeball forward on its x-axis
- Contracting the two fingers moves the eyeball backwards on the x-axis

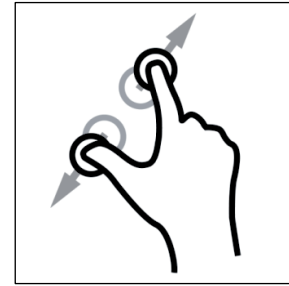


Figure 3-19 Two-finger pinch gesture

It is assumed that a typical two-finger pinch gesture width s_w is 100 mm, which is translated to a surging distance d_{surge} in the VE.

The typical gesture is using one hand with two fingers. To conquer larger distances, the gesture using two hands with one finger each could be easily used.

Translation and Scaling

The translation from the distance of moved fingers by using a gesture to the distance of the eyeball moved in the virtual room is proposed as follows.

For rotations (yaw_e and $pitch_e$):

The scale factor should be linear. For [A][1] swiping half of the VE viewport width ve_w equals 180° of yaw rotation. For [A][2] swiping half of the VE viewport height ve_h equals 90° of pitch rotation.

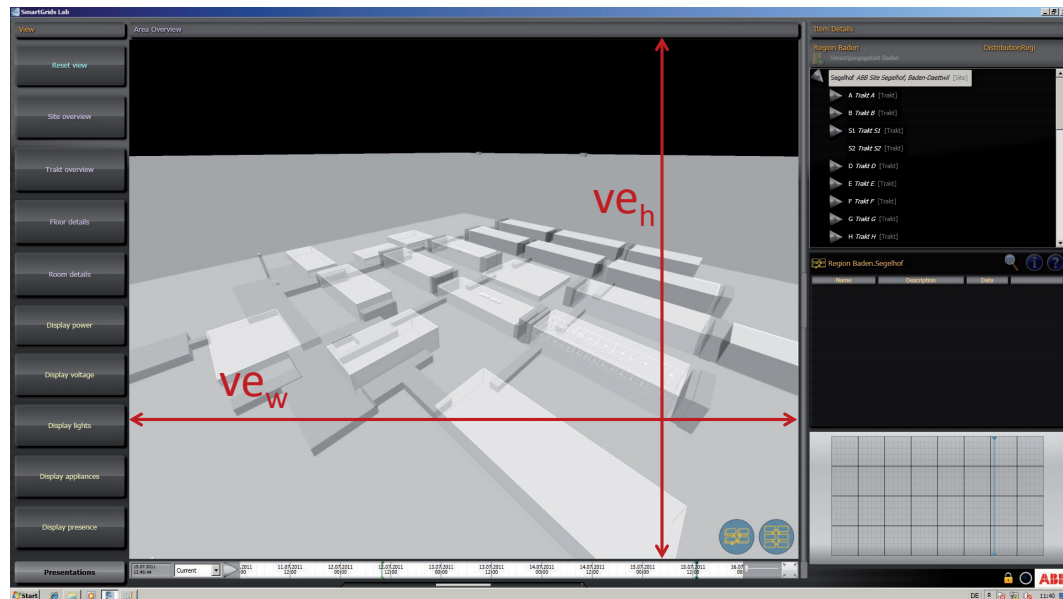


Figure 3-20 SGD screen with definition of virtual environment viewport width and height

For panning (pan_e):

The scale factor is a function of the eyeball height h_e . The translation of finger movement p_w for [B][4] and [B][5] needs to be equal. The proposed function of the scale factor is illustrated in Figure 3-21.

For heading (surge_e):

The scale factor is a function of the eyeball height h_e . The proposed function for translation of finger movement s_w for [C][3] is illustrated in Figure 3-21.

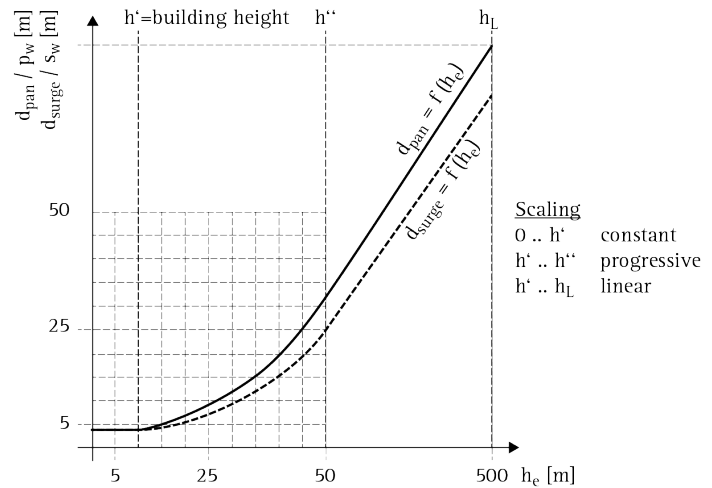


Figure 3-21 Scaling function for panning and surging

Limitations

For pitch_e a limitation must be implemented from 0° (looking to the horizon) to 90° (looking straight down).

The range of navigation within the model should also be limited to prevent total loss of orientation and to allow reasonable movements within the model. Therefore the suggestion is to limit the maximum height h_L (refer also to Figure 3-21) and the maximum distance of the eyeball from the center of the model to e.g. 500 m.

Acceleration

Panning (pan_e) and heading (surge_e) range and precision can be improved by using an acceleration factor depending on the finger's velocity (scaled velocity according to (Ware, et al., 1990)). Typical parameters for finger velocity and acceleration factors as well as the usefulness of defining a minimum velocity (offset) need to be investigated during the implementation phase (refer also to Figure 3-22).

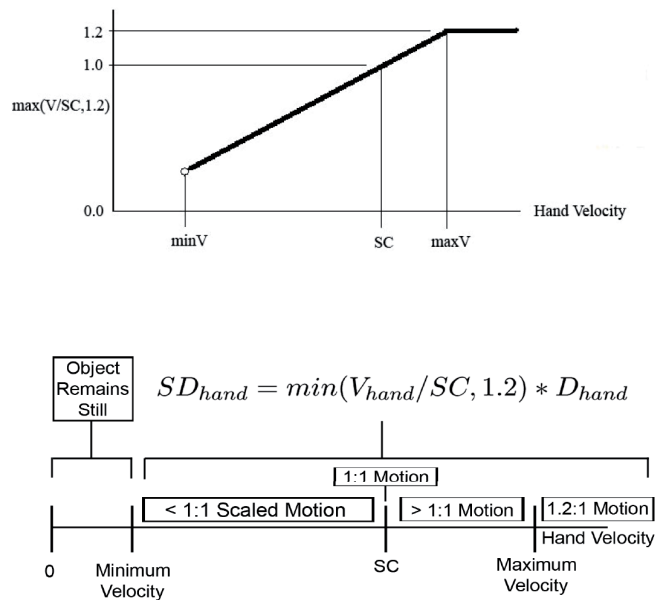


Figure 3-22 Calculation of scaled velocity according to (Ware, et al., 1990)

3.6.5 Implementation

For the implementation of above proposed solutions a compromise had to be found between available development resources, time, and effectiveness of the proposed items. Therefore not all proposed items could be implemented.

During the implementation phase different items were tested by the developer as well as optimized by the help of *hallway tests*.

The implementation was done in a way that different properties could be configured to set the desired behavior of the model, widget, and gestures. The implementation is described as used for the second evaluation. A full description of the “*Configurable Properties*” can be found in the *Addendum*.

Implementation of General Proposals

Key-instructions and help:

Was not implemented.

Context information:

The proposed context information was not implemented.

Delays and rubber band effects:

All programmed delays and rubber band effects were disabled.

Landmarks and landscape:

Proposed landmarks and landscapes were not implemented.

Improved visual design:

The proposed items were not implemented. In order to keep the user’s focus on the VE viewport, the object tree-view and object info viewports were hidden for novice users (as shown in *Figure 3-23*).

Implementation of Proposal A: Scene-in-Hand Metaphor with Widget Interaction

Redesigned widget:

The redesigned widget was implemented slightly differently than proposed. *Figure 3-23* illustrates how the widget was implemented.

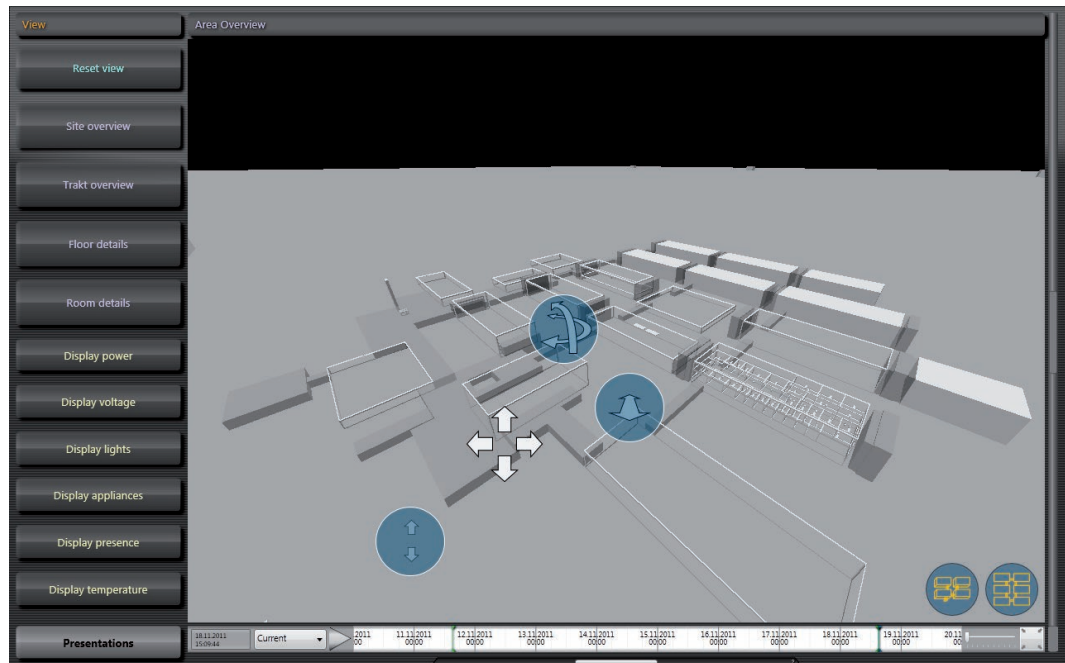


Figure 3-23 SGD screen with hidden object tree-view and object info viewports and the redesigned widget as implemented

The icons were designed more distinct and were positioned optimally for one-hand operation and right hand usage.

The delay for the widget to appear was removed:

For the pan function the original icon was used instead of removing the icon as proposed. The function is activated automatically and without delay, when the user touches and moves his finger. Swiping left/right and up/down pans the model into the respective direction (pan_e). The other icons for pitch/rotate, zoom, and elevation are displayed slightly transparent.

The zoom function works in vertical direction instead of horizontal as proposed, to make it more ergonomic to operate. Tapping the zoom control with a second finger activates the function while the symbol gets green and less transparent. The other (inactive) icons are displayed more transparently (refer also to Figure 3-24). Swiping down zooms into the model and swiping up zooms out of the model. The zoom function is released, when the user withdraws his fingers from the touch-screen.

The pitch and rotation function is activated and used the same way as the zoom control described above. Swiping to the left rotates the model clockwise and swiping to the right counter-clockwise. Swiping down pitches the model towards a bird's-eye view and swiping up pitches the model towards a horizontal position. The translation factors were implemented as proposed.

The elevation control is similar to the other controls. Swiping down moves the point of view to a higher altitude and swiping up brings the point of view towards the ground plane.

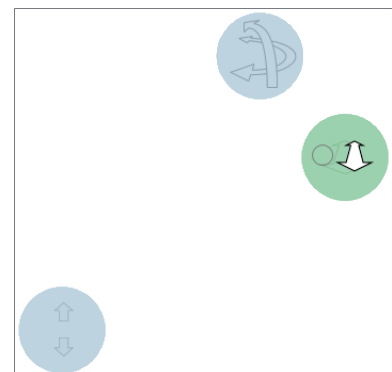


Figure 3-24 New widget as implemented with activated zoom function

Limitation of gains and area of action:

- The proposed limitation was not implemented
- The pivot for zoom, rotate and pitch was set to the center of the VE viewport to make the pivot transparent to the user
- A simplified algorithm was implemented for scaling and transformation for the widget functions zoom, pan and elevation. The scaling is absolutely depending on the current view distance (eye to VE viewport center distance)

On-the-fly help:

The proposed short help message for the widget controls was not implemented.

Disabled info pop-ups:

The info pop-ups were simply disabled instead of layering them behind the widget as proposed.

Implementation of Proposal B: Eyeball-in-Hand Metaphor with Gestures-only Interaction

The *eyeball-in-hand* metaphor with the 5 DOF and its gestures (yaw_e, pitch_e, surge_e, sway_e and heave_e) was implemented as proposed.

Gestures:

The directions for two-finger swipe gestures for rotations (yaw_e [1] and pitch_e [2]) were reversed compared to the proposals:

- For swiping left, the eyeball turns left as well. Swiping right turns the eyeball right
- For swiping up, the eyeball turns up. Swiping down turns the eyeball down

Translation and scaling:

- The scaling for all rotations was implemented linear as proposed, as well as the translation for rotation (yaw_e)
- A higher resolution for the pitch translation was chosen, in order that a swipe gesture took the full viewport height v_{e_h} to pitch 90°
- The scale factor for panning and heading was implemented similarly as proposed, but with a linear scaling factor between 4 m and 320 m and constant factor below 4 m and above 320 m (h_e)

Limitations:

The pitch limitation in the range of 0° to a maximum of 90° was implemented as proposed, whereas the limitation of the possible navigation area (maximum distance from VE center and height) was not implemented.

Acceleration:

Acceleration factors were not implemented

Set-up for Second Evaluation

During implementation and *hallway testing*, an optimal set-up for the second evaluation was investigated. Though, the *hallway tests* on the desired 42" touch-screen failed as two-finger gestures used in solution B could not be detected, due to the lack of resolution and accuracy of the system. Hence, the smaller 21" touch-screen had to be taken instead.

The following table gives an overview of the chosen SW configuration for the two solutions prepared for the second usability test. A full description of the “*Configurable Properties*” can be found in the *Addendum*.

Table 3-6 Software configuration for solution A and B as used in the second evaluation

SW Property	Effect	Notes	Solution
<i>lofi</i>	Sets lower fidelity 3D rendering	Required for 11" tablet and 21" desktop PC	A & B
<i>synthetic</i>	Uses simulated data	Increases PC performance	A & B
<i>fullscreen</i>	Sets window to fullscreen after startup		A & B
<i>eyeballinhand</i>	Switches model to <i>eyeball-in-hand</i> mode		B
<i>moveabsolute</i>	Sets scaling for move to absolute	Eye to screen-center as scale-factor	A
<i>scalespeedbyheight</i>	Reduces scaling factor below 10 meters height	For surge, sway and heave	B
<i>rotateatcenter</i>	Sets the rotation center to viewport center		A
<i>zoomatcenter</i>	Sets the zoom center to viewport center		A
<i>simplewidget</i>	Uses the new (simplified) widget		A
<i>nopopup</i>	Disables object info flags		A & B
<i>gesturemode</i>	Activates gestures		B

3.7 Results from the Second Evaluation with Proposed Solutions

The second evaluation was set up in three parts: a usability test, interview, and a questionnaire according to ISO 9241-110

- The aim of the usability test was to find remaining as well as new usability issues of the implemented solutions
- The interviews should answer questions about intuitiveness of both solutions, usability and preferences of gestures or widget as well as of the implemented VE metaphor from the participants' view
- The questionnaire should finally give a quantitative result of the suitability of solution A and B as well as compare them to the initial solution

All usability issues and interviews were logged, compiled and summarized. Finally, the solutions were checked against the usability issues found in the first evaluation and compared with each other.

3.7.1 Usability Issues Observed During the Usability Test

The usability test was evaluated focusing on specific issues and questions relating to model, widget and gestures behavior as well as on the metaphors, intuitiveness, and completion of the tasks.

The usability issues observed in the usability test are listed below with their relation to the usability issues (Uxx) and user expectations (Exx) from the first evaluation. The complete record of the “*Usability Evaluation 2 - Issues*” is available in the *Addendum*.

General Model Behavior

Relating user expectations and usability issues: E17, U18, U19, U28, and U31

Was the user irritated by certain designs, colors, or color changes of the model?

- The color of an object changes to white when selected. Especially “big” objects such as the ground plate of the VE confused three out of ten participants. They did not know what it was meant for
- Double tap sets the view to the touched object and zooms (grab) the object. If e.g. the model is touched outside the campus, the view is set to a far outreached point as shown in *Figure 3-25* (refer also to U13, which is not implemented)

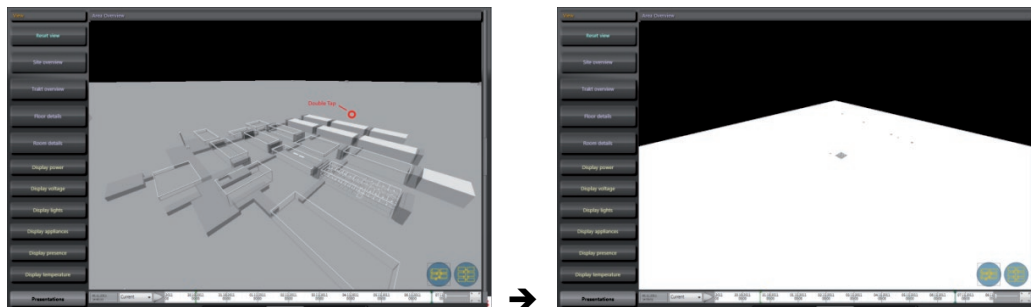


Figure 3-25 Double tap on the ground plate (left) sets viewpoint to a far outreached point (right)

Behavior of the Model in Solution A: Scene-in-Hand Metaphor with Widget Interaction

Relating user expectations and usability issues: E17, U18, U19, U28, and U31

Did errors occur (e.g. system did not react)?

Tapping on another place within delay time (time for function buttons to hide) sets the pan icon to the new touch-point. The correct function would be to display the function buttons immediately around the new touch-point (refer also to *Figure 3-26*).

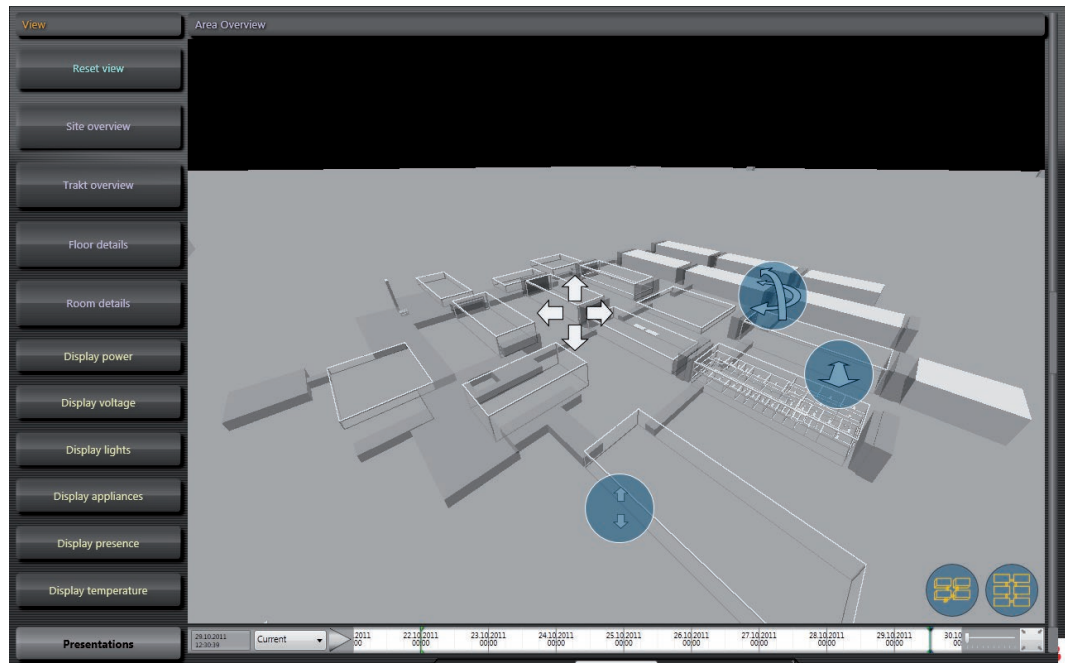


Figure 3-26 Widget error when tapping within hiding time

Was the user irritated by model jumps?

No model jumps occurred.

Was the user irritated by delays and cumbersome reaction of the model?

No irritations of participants could be observed; the system reacted smoothly and was smoothly controllable.

Behavior of the Model in Solution B: Eyeball-in-Hand Metaphor with Gestures-only Interaction

Did errors occur (e.g. system did not react)?

No system errors occurred.

Was the user irritated by model jumps?

- Seven out of ten participants faced model jumps (model shifts from some meters up to 100 m away), but they were not concerned or confused about such reaction, they just continued with their task
- It seems that when doing fast finger movements the sensor interpretation by the system gets stuck (this behavior could not be seen on the X201 tablet, which had a capacitive touch-screen and was more powerful). Some model jumps occurred when releasing the finger after panning (like if it had detected a double tap when releasing)
- It seems that the touch-screen's optical sensors interpret a double tap when users touch the screen rather smoothly. Optical sensors are also quite picky for interfering fingers resulting in model jumps
- Two zoom jumps occurred without doing any zoom (grab) gesture

Was the user irritated by delays and cumbersome reaction of the model?

- No irritations of participants could be observed, although the system reacted slower than with the *scene-in-hand* metaphor
- Participants were more irritated by gesture detection problems rather than by the reaction of the model

Widget Behavior

Relating user expectations and usability issues: E01, E06, E10, E17, E18, U01, U09, U20, and U28

Did widget jumps occur, and was the user irritated?

No widget jumps occurred.

Was the user irritated by delays and cumbersome operation?

No irritations of participants could be observed; the widget reacted smoothly and was smoothly controllable.

Did the user have problems operating the widget?

- For five participants the widget disappeared too fast in order to select the functions within time
- Three participants did not realize that they could release the forefinger to use a function and had some difficulties to control the widget with one hand and two fingers
- Only one participant used both hands to operate the widget
- One participant mentioned that he did not understand that panning requires only one finger and all other functions require two fingers
- All participants failed the test, where they had to rotate within a building
- Rotation within a building or near buildings with horizontal view angle is not useful through rotation (yaw_s) at the center of the model. The user cannot relate to the pivot and gets irritated
- Calling-up the widget by touching close to the viewport border moves some function buttons outside the screen as shown in *Figure 3-27*. One participant was confused about this and did not realize to call-up the widget more in the center of the screen instead. This behavior may indicate that the participant has not really understood the setting of the pivot

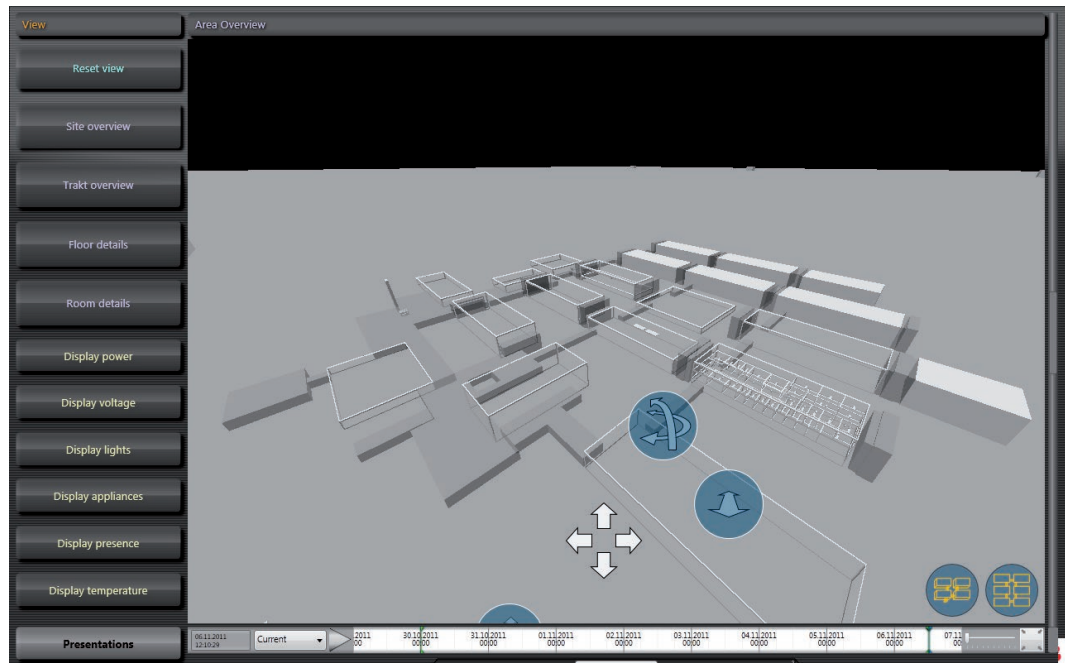


Figure 3-27 Calling-up the widget close to the viewport borders moves some function buttons outside the screen

Did the widget operate as the user expected (axes, directions, scaling-factors)?

- Three participants ignored the widget function buttons at the beginning of the test
- It seemed that the affordance to use the function buttons was not distinct enough
- The scaling of the pan function when moving within buildings was slightly too big
- Two participants expected function buttons to be activated. They also expected to use the function by moving the finger like with panning
- No participant seemed to be irritated by nor complained about gesture/widget directions

Gestures Behavior

Relating user expectations and usability issues from first evaluation are E14, U25.

Was the user irritated by delays and cumbersome operation?

- Six out of ten participants executed rotation and/or pitch gesture unintentionally, but due to cumbersome system reactions they did not realize and could not repeat this gesture when needed. We assume that some participants were not able to explore and learn two-finger swipe gestures due to cumbersome system reactions, when executing the gesture unintentionally. The participants could not relate the reaction of the system to the executed gesture because of the reaction delay and by jerky movements
- Five participants faced the problem that the system sometimes struggled to detect two-finger swipe gestures at all. After releasing the fingers for about half of a second, the detection then usually worked

Did interferences occur while operating (e.g. touching with another finger), and was the user irritated?

No interferences occurred unless those referred to in chapter “*Behavior of the Model in Solution B: Eyeball-in-Hand Metaphor with Gestures-only Interaction*” on page 51.

Did the user have problems executing the gestures?

One participant found that the two-finger swipe gestures (movements) were unnatural and he struggled operating them correctly.

Did the gestures operate as the user expected (axes, directions, scaling-factors)?

- Neither irritations of participants could be observed nor did participants complain about expecting some other behavior of a gesture. One participant wanted to use double tap to zoom into a building
- No participant seemed to be irritated nor complained about gesture directions

Issues Related to the Model Metaphor in Solution A: Scene-in-Hand Metaphor with Widget Interaction

Relating user expectations and usability issues: U08, U30, and U34

Was the user irritated by the way he had to move (within) the model?

- Three participants did not understand the pan function, as soon as they had to move through a building (corridor). They did not understand that they moved the model on the same height by panning
- Four participants did not realize they could use pan in order to move through a building and used zoom instead. This behavior may indicate that the participants did not understand the principle of the model respectively the difference between panning and zooming
- Participants did not use the elevation function and did not realize the difference between elevation and pitch when navigating through buildings. In this case, the elevation function could be moved from the widget to a separate side bar

Was the user irritated by the viewpoint and/or point of operation (pivot)?

- No irritations of participants could be observed unless the problem with rotating within a building referred to in chapter “*Widget Behavior*” on page 52. Only one participant mentioned that he did not know where the pivot was set for rotation
- It seems that participants usually did not realize and were not confused, where the pivot for rotation and zooming was set

Issues Related to the Model Metaphor in Solution B: Eyeball-in-Hand Metaphor with Gestures-only Interaction

Relating user expectations and usability issues: U08, U30, and U34

Was the user irritated by the way he had to move (within) the model?

- Three participants did not realize that they had to zoom (grab) to move through a building and tried to use pan gesture instead. This behavior may indicate that the users have not understood the *eyeball-in-hand* metaphor respectively the difference between panning (pan) and zooming (grab)
- Five participants were irritated by the wide angle perspective. They got the impression that panning somehow rotated the model

- No participant was confused by panning on the z-axis (heave), they just used zoom-out to get more height when e.g. being too close to the building
- Eight of ten participants did not use the pitch gesture to get 90° horizontal view in order to “walk horizontally” on the same height by zooming (grab). Only two participants realized to set the pitch to 90° and zoom

Was the user irritated by the viewpoint and/or point of operation (pivot)?

No irritations of participants could be observed. One participant expected the zoom pivot in the middle of the two fingers.

Intuitiveness of the Widget and Gestures

The intuitiveness of the different navigation functions in solution A and B were rated in a scale of one to five, whereas 1 meant the participant found the function very easy, 3 meant the participant had difficulties to find the function and 5 meant that the participant was unable to find and use the function at all. The participants were observed on executing the different implemented widget functions and gestures as well as unimplemented gestures which users wanted to use intuitively. The following table gives an overview on all widget functions and gestures as well as executed gestures which were not supported.

Table 3-7 Intuitiveness rating of widget functions and gestures

Navigation Function	Solution A: Widget	Solution B: Gestures
<i>Pan (pans/pan_e)</i>	1	1
<i>Zoom (grab)</i>	2.8	1.6
<i>Rotate (surge_s/surge_e)</i>	2.4	4.9
<i>Rotate using 1-finger arc gesture* (-/yaw_e)</i>	–	2.4
<i>Rotate using circular 2-finger twist gesture* (-/yaw_e)</i>	–	2
<i>Pitch (pitch_s/pitch_e)</i>	2.4	4.8
<i>Elevation (surge_s/–)</i>	3.1	n.a.

1 = very easy, 3 = difficult, 5 = unable, * not implemented gesture

The results show a differential picture. Panning was very intuitive to all participants as well as zooming with gestures, but for rotating the results varied substantially. Rotation using the widget in solution A was quite intuitive for the participants, but in solution B it was merely impossible for them to discover. Instead they tried either rotating with a 1-finger arc gesture or a circular 2-finger twist gesture. Pitching in solution B only was hardly found by anyone. Only two participants discovered this function, whereas the same function in solution A was quite intuitively found.

Task Completion with Solution A: Scene-in-Hand Metaphor with Widget Interaction

How did the user complete the different tasks?

All participants were able to complete all the tasks within a mean time of about 9 minutes (refer also to “Usability Evaluation 2 - Intuitiveness Matrix” in the *Addendum*). No instructions were given at all. Exceptions were made in task 4 (refer to “Usability Evaluation 2 - Test Scenario” in the *Addendum*), where no participant could rotate within a building as described in chapter “Widget Behavior” (on page 52) as well as for one participant who was not able to find out other functions than panning without getting any hint.

Task Completion with Solution B: Eyeball-in-Hand Metaphor with Gestures-only Interaction

How did the user complete the different tasks?

All participants were able to complete all the tasks within a mean time of about 11 minutes (refer to “Usability Evaluation 2 - Intuitiveness Matrix” in the *Addendum*). All participants required some hints to find out the two-finger swipe gestures. One participant was not able to find out other gestures than panning without getting any hint.

3.7.2 Participants' Statements about the two Solutions

The participants were interviewed after the usability test. Their statements were collected and compiled in order to answer the following questions.

General Intuitiveness of Solution A Compared with Solution B

- Both solutions were equally rated relating to their general intuitiveness. 40 % of the participants found that they were getting better along with solution A, whereas 40 % rated solution B as the better solution and 20 % were indifferent
- The symbols of the widget may give some initial help and some clues to its affordance
- Some participants said that they preferred solution B if initial help had been provided

Intuitiveness of the Widget

- Four of ten participants said that they understood the meaning of the symbols quite fast. On the other hand there were two participants, who did not understand the functions of the symbols. Even though most of the participants recognized the functions, they had some troubles using them. So they did not know how to activate the functions nor did they know how to move them once activated (affordance). Nevertheless, the symbols of the widget could tell the participants how the model could be navigated
- There might be a bias regarding the conformity with participants' expectations because many test participants were familiar with AutoCAD, where the navigation is similar

Intuitiveness of the Gestures

- Participants who never experienced the usage of gestures, missed some initial help. Therefore initial help, like short animations on how to use gestures would give the participants first clues
- It seems that participants are only capable using a pure gesture solution if they have used gestures before or learned about them from observing other people (previous knowledge)
- Three participants said that they did not know how to rotate, hence the implemented rotate gesture (two-finger swipe) does not seem to map the participants' expectations
- Gestures are intuitive as long as participants recognize a direct relationship in movement between the gesture itself and the model

Navigating with the Use of a Widget or Gestures-Only

- There is no clear distinction whether participants prefer navigating with a widget or with gestures-only. So, more than half of the participants mentioned that the symbols of the widget helped them to find out the functions because they are clear and tell them what to do
- There is also no remarkable difference whether participants felt that they could control the model better with either solution. Advantage of a solution without a widget is that there is no need for buttons and therefore the complete screen is visible while navigating
- Again, there is no preference visible of the participants' answers regarding the handling of the two solutions. Three participants found that the widget was more comfortable to their fingers, whereas three found the gestures were more comfortable and three other participants were indifferent

Functioning of Gestures Operation

- More than six participants found the pan and zoom function was easy to use, but concerns were mentioned regarding the rotate function. That is why most of the suggestions for improvement came up for rotating (two-finger twist, circling using one finger). Other notable ideas were mentioned for zooming (pressing on the model, circle movement with one finger), or adding alternative navigation elements (slider button)
- Five participants knew gestures already from their own smartphones or have learned about them from their colleagues

Preferences for Model Metaphor (Scene-in-Hand or Eyeball-in-Hand)

- Comparing the two 3D models in terms of the behavior and what the participants expected, does not give a clear picture. The numbers of participants who preferred the one or the other solution are about the same
- Eight participants could not find any differences between the two solutions
- Only two participants mentioned that it was easier to rotate in solution A (*scene-in-hand*) while standing outside a building but in contrary it was easier to rotate in solution B (*eyeball-in-hand*) while standing inside a building

General Remarks

There were some complaints about the system performance and its reliability.

3.7.3 Overview of Resolution of Usability Issues and User Expectations

The following tables summarize the observations made and statements given by the participants during the second evaluation and give an overview about the degree of resolution of the main usability issues and user expectations.

Table 3-8 Overview of solved high priority usability issues

Problem	ID	Solved w. Solution A	Solved w. Solution B
<i>Widget jumped</i>	U09	yes	n.a.
<i>Widget not appearing</i>	U11	yes*	n.a.
<i>Double-tap does not respond</i>	U13	no	n.a.
<i>Model jump</i>	U30	yes	partly
<i>Zoom jump</i>	U18	yes	partly
<i>Difficulties with learning gestures</i>	U20	partly	partly
<i>Irritating info pop-up</i>	U19	yes	yes
<i>Info pop-up overlaps widget</i>	U31	yes	n.a.
<i>Wrong control chosen</i>	U01	partly	n.a.
<i>Does not understand reset icons</i>	U02	no	no
<i>Elevation in wrong direction</i>	U34	yes	yes
<i>Mental model; first person view</i>	U08	n.a.	yes
<i>Two-finger gestures expected</i>	U25	no	yes
<i>It reacts too slow</i>	U28	yes	partly

* no specific solution implemented, but solved with other measures

Table 3-9 High priority user expectations

Expectation	ID	Solved w. Solution A	Solved w. Solution B
<i>Faster reaction of system & widget</i>	E17	yes	partly (for system)
<i>No delay for the widget to display</i>	E18	yes	n.a.
<i>Use uniform pattern for interacting</i>	E10	yes	n.a.
<i>Omit the widget and just use gestures</i>	E14	no	yes
<i>Widget must be intuitive to use (how to get it and how to keep it)</i>	E01	partly	n.a.
<i>If the widget is under my finger, it should stay there</i>	E06	partly	n.a.
<i>Key instructions</i>	E37	no	no
<i>Help instructions for the functions</i>	E40	no	no
<i>Descriptions on the buildings themselves</i>	E29	no	no
<i>Landmarks to orientate</i>	E32	no	no
<i>Colors to distinguish different things</i>	E33	no	no

3.7.4 Rating and Preferences for Solution A and B

Results from the questionnaire show that solution A has brought general improvements and a higher rating in all aspects compared to the initial solution. Comparing solution A with solution B gives a similar picture.

The comparability of solution A and B might be limited because the quality of the gesture and system behavior in solution B was on a lower level than in A. Next to this, the missing implementation of key instructions and help revealed to be a higher handicap for solution B compared to solution A.

According to the results of the questionnaire, solution A clearly seems to be the preferred solution. But reflecting the results with the participants' statements made in

the interviews, the picture gets less definite. Participants' statements relating to intuitiveness, widget or gestures and model implementation, were quite balanced between both solutions.

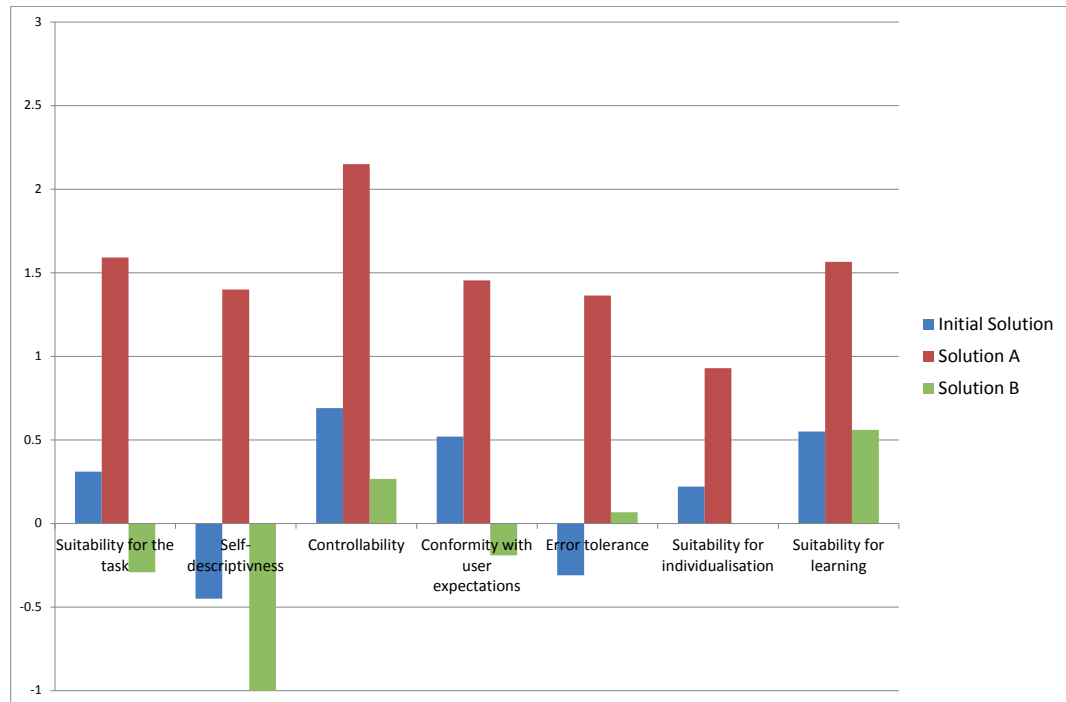


Figure 3-28 Rating of initial solution, solution A and B according to ISO questionnaire

4 Discussion of Results and Conclusion

The following chapters discuss the conclusions of the theoretical aspects including the resulting three theses and verify them with the findings from the practical part. After that the findings from both theoretical and practical part are summarized and explained as well as what implication they have on the SGD. Finally an outlook on future work and open matters are given.

4.1 Theory versus Practice

Thesis 1: Interaction with sole gestures is more intuitive than interactions with a widget respectively using some kind of UI elements.

From the theoretical point of view, a gestures-only navigation has some advantages compared to a solution where widgets are used. As mentioned in chapter “Input Devices” (on page 6) in the theoretical part of this document, a study illustrates that multi-touch gestures are very intuitive for users, requiring very little instruction of practice (Fu, et al., 2010). This is supported by the observations in the first usability evaluation, because participants often first tried to use gestures such as pinch for zooming. Some participants even suggested in the interview to omit the widget and use iPhone-like gestures instead. On the other side when asking interviewees what solution they preferred in the second usability evaluation – widget or gestures-only – there was no clear winner. Furthermore the widget version was rated far better in the ISO standard questionnaire regarding the indicators for intuitiveness, being self-descriptiveness, conformity with user expectations and suitability for learning. It can be assumed that if no help is provided otherwise, widgets can give some hints to users on how to navigate a graphical user interface.

The gestures-only version did not get much positive points in the ISO standard questionnaire and the participants did not find out some gestures like for the rotation function at all. These facts may indicate two things. Firstly users need to have some experience in using gestures, some sort of pre-knowledge. Even if they never used gestures before but observed other people swiping around on their smart phones can tempt users to try out gestures on a multi-touch device. So giving some initial help like a short animation can encourage users to try out gestures on a multi-touch-screen that is new to them. The second fact that hinders users to learn gestures and what could also be observed in both usability evaluations, is hardware-related. But this factor will be discussed further down.

Designing a gestures-only navigation requires additional things to take into account. Even if there are many natural gestures for a given intended action, they have to be selected and designed carefully for the context in use. As mentioned in chapter 2.2.6

a study showed that the choice of interaction was influenced by prior and subsequent interactions as well as the social context, age and users' intention (Hinrichs, et al., 2011). This could be observed in the usability evaluations where elder participants, who possibly never used a multi-touch device before, had more troubles finding out gestures.

Even though the widget version in the second evaluation seemed to be performing better there are some concerns related to widgets. As explained in chapter 2.2.2 widgets can overlap or interfere with other important graphical objects and therefore annoy users. As outlined in the corresponding sections in chapters 3.5 and 3.7 in both usability evaluations participants often just ignored the widget appearing in a first attempt. In one case the user got irritated because some part of the widget disappeared beyond the screen as shown in *Figure 3-27*. On the other hand implementing static widgets and placing them somewhere to the edge of the screen is neither a good solution. Fu *et al.* (2010) state that interaction has to be performed at the locality chosen by the user (see section "Interaction Locality" in chapter 2.3) otherwise the point of control has to be predefined by the system and therefore the pivot is usually set to the screen center. This in turn can be unsatisfactory as the behavior for operations can be different than expected. Because of other reasons that are explained in chapter 3.6.5 the pivot for the widget solution has been set to the screen center. Although this should make the pivot transparent to users, this irritated them at the same time. Especially when e.g. rotating the model in order to turn themselves around for looking back inside a corridor.

Even though widgets can help novice users to find out what functionality the system offers, their affordance is not for granted. Participants had troubles understanding how to operate the widget as observed in both usability evaluations (see section "Widget Behavior and Affordance" in chapter 3.5.1 and section "Widget Behavior" in chapter 3.7.1). There were also some participants who found out certain functions in the first attempt but could not recall them after getting instructions as illustrated in *Table 3-3*. Therefore a carefully designed widget is crucial for an intuitive system.

The thesis that interaction with sole gestures was more intuitive than interactions with a widget respectively can neither be verified nor falsified. Nevertheless there are some important findings that can be adapted to the SGD.

Thesis 2: The *eyeball-in-hand* metaphor in the context of the SGD is more intuitive than the *scene-in-hand* metaphor.

The first usability evaluation of the SGD revealed troubles that participants had controlling the movements of the virtual environment. As mentioned in chapter 3.5.1 the model often jumped unexpectedly while panning or zooming over a certain range of the screen. This led to the assumption that this problem would originate from a fuzzy setting of the pivot by the system. As stated in "Setting a Pivot" in chapter 2.3 the position of the pivot is clear with the *eyeball-in-hand* metaphor, as it is the eyeball itself (Ware, et al., 1990). Therefore a change of the behavioral metaphor was proposed to solve such unexpected movements of the model. On the other hand the same authors discovered in their study that for a certain task there is no winner or loser between both metaphors. As they told, SIH was better for the cube-task, where the observer stands outside of the object and EIH was better for the maze-task, where the observer stands inside of the object. Stoev & Schmalstieg (2002) point to the same direction where they found that SIH metaphor is more appropriate for traveling to far destinations while the EIH metaphor is more suitable for adjusting the viewpoint at the current location (refer also to chapters 2.2.4 and 2.2.5).

This could be approved by the usability tests within this work. As already said, one software version being tested in the second usability evaluation was based on the EIH metaphor. The findings illustrated in chapter 3.7 revealed that the troubles especially for rotating were different for both metaphors. With the EIH version, participants could easily turn around in a corridor but got lost while standing outside a building and trying to rotate (yaw). The opposite could be observed with SIH. The participants found it easy to rotate the model while standing outside a building, but could not manage looking back while standing in a corridor. It has to be admitted that the SIH version had the pivot set to the screen center, which is another factor for the latter problem above. But even the pivot was set to the most feasible object by the system the user would be lost while rotating because he almost never stands near an object.

Thesis 2 can be falsified not only from a theoretical point of view but also from practical results, because there is no direct correlation between intuitiveness of the SGD and the inherent metaphor. As already mentioned in chapter 2.5 the choice of the metaphors depends on the tasks to be performed. Whether a combination of metaphors really increases intuitiveness of the SGD could not be approved within this work, but this is recommended to be done in future improvements.

Another interesting finding from the second evaluation was that almost no participants were aware of the two different metaphors. As illustrated in chapter 3.7.2 most participants said in the interview that they did not notice any difference between both versions regarding model behavior when rotating with one or the other metaphor. Some participants also did not realize to use pan in order to move through a building with SIH and used zoom instead and in contrary they did not use zoom to move through a building with EIH and used pan instead. The participants might not have perceived any difference because the gesture directions for EIH were transformed similar to SIH or because of high concentration on the task using the widget or gestures during operation and navigation.

Thesis 3: An accurate and reliable technology and an error-tolerant implementation are key aspects to intuitiveness and learnability.

As described in chapter 2.5 hardly no literature could be found that supports the above-mentioned thesis. It has also been argued in the same chapter that freedom of control, interaction locality as well as the implementation of metaphors have an impact on how interaction is perceived. Apart from interaction locality these statements could not be approved by the usability evaluations. In terms of interaction locality and according to the findings in usability evaluation 2 (see “Widget Behavior” in chapter 3.7.1) all participants failed to rotate on place while they stood within a building with software version SIH where the pivot was set to the center of the screen instead of their locality.

According to Jordan (2000) there is no usability without functionality. If accuracy, reliability and error tolerance is seen as preconditions of functionality, these factors are vital to usability hence to intuitiveness and especially to learnability. Very often participants executed rotation and pitch gestures unintentionally, but with cumbersome system reaction they did not realize what function was mapped to the gesture they just used and so they could not learn the gestures (see also “Gestures Behavior” in chapter 3.7.1). On other instances participants tried out gestures deliberately but the system reacted erroneously or just hanged, so the participant assumed that this gesture was not provided by the system therefore he did not take a second chance. This was particularly the case for two-finger swipe gestures.

Consequently the findings in both usability evaluations strongly support the thesis above.

4.2 Conclusion for SGD

Gesture-Based Interaction

Gesture-based interactions are generally accepted and perceived positively by novice users as concluded from the theoretical part of this work. Even though using gestures-only is very promising this could not have been approved explicitly in practice. The problems for this are described above and can be rooted back basically to hardware deficiency and troubles with the rotation gesture. It is advised to use both twist gesture and two-finger swipe. Nevertheless the evaluations showed that users try out well-known gestures first on a multi-touch-screen. After all it is suggested to use a gestures-only navigation for the SGD. In order to build a system that can be operated intuitively, the gestures have to be evaluated carefully with precisely adjusted scaling factors. To enhance intuitiveness even further additional widgets for seldomly used functions can be implemented such as for elevation. They can be placed somewhere to the border of the screen.

Widget-based interactions are not useless in general. Nevertheless there are some disadvantages as observed in the evaluations since users often just ignored the widget or the widget overlaid some part of the model. If for any other reason widgets should be implemented, they have to be designed and evaluated carefully in terms of affordance, functionality and symbol layout. On-the-fly help should be provided in order to support novice users to figure out how to operate a widget.

Combination of Scene-in-Hand and Eyeball-in-Hand

A combination of both metaphors SIH and EIH is optimal for a 3D on-screen navigation as used for the SGD. As explained in the theoretical part both metaphors have their pros and cons for certain tasks. Also the evaluations showed that one metaphor seems to be perfect for some situations and fails in others where the other metaphor is better and vice versa. But where exactly the system should switch from one to the other metaphor cannot be defined easily. This may require further investigations. One approach would be letting the user decide what metaphor to choose depending on the gestures used. In this case different gestures for the same function would be implemented. While using the two-finger swipe gesture the system rotates in the EIH mode and using the two-finger pinch gesture the system rotates in the SIH mode.

Another very important aspect for an intuitive 3D system is how and where the pivot is set. Studies in the theoretical part as well as the findings in the practical part of this work suggest setting the pivot to the locality of action. This is usually an object closest to where the user points his fingers. In order to make the pivot understandable and visible to the user it is advised to indicate the pivot as a sort of cross line while the model is being transformed.

Limitations

Limiting gains and areas of interaction as described in chapter 3.6.3 are suggested. This is in order to omit situations where users got lost because of fast and unexpected movements of the virtual environment or even vanishing of the model to infinity. This correction should especially become active while the system is in the SIH mode.

Hardware Improvements

Although testing and evaluating hardware is out of scope within this work it is recommended to change the multi-touch-screen hardware being used for SGD. During the evaluations inaccurate and erroneous reactions of the system could be observed that not only confused users but also hindered them from learning gestures. If the system does not provide proper functionality there is no usability. It can be assumed that multi-touch-screen technology, where optical sensors take up the movements of the fingers are not accurate enough for gesture-like on-screen navigation. They may be useful for selecting buttons but not for gestures like two-finger swiping and pinching. If a more precise touch-screen technology was used like capacitive screens, gesture detection would be strongly improved and widget and model jumps would be drastically reduced. Even if an experienced user is able to handle a cumbersome touch-screen using optical sensors it is not error-tolerant enough for novice users. Besides that, the hardware performance must provide a fast reacting system in order to have a smooth transformation of the 3D model.

Help and Assistance

Providing key-instructions and help as mentioned in chapter 3.6.2 would support new users to get along with the SGD quickly. Context information of active objects should be provided to give users quick information about object. Implementing landmarks, like the fountain in front of the Segelhof campus, could increase the orientation on the virtual environment. It is suggested to improve the visual design by creating active objects more realistically and adding color in order to expand orientation especially when zoomed into details.

The double-tap function should also be corrected in a way that when the user taps accidentally between buildings, i.e. on the background, the zoom center should be focused to the nearest building instead of the far background. Setting the pivot to the nearest object as already described above could solve this.

4.3 Future Work

The following topics could not have been covered in this work and should be investigated in future work:

Redesign Gestures

The gestures of the improved software were tested but they need to be looked at again. They have to be redesigned and evaluated in the following terms:

- Evaluate in detail what gestures work well for SGD
- Evaluate multi-touch gestures where more than two fingers are used
- Evaluate mapping of gestures to axis with respect to the metaphor used
- Evaluate gesture direction with respect to the model movements

Combination of Scene-in-Hand and Eyeball-in-Hand

The above-mentioned suggestion to combine both metaphors has to be investigated further in terms of the following subjects:

- Evaluate at what conditions the metaphor is changed by the system
- Evaluate what gestures to use with what metaphor and when letting the user change between SIH and EIH
- Evaluate what of the two solutions above are more usable

Scaling and Pivot Setting

Translation and scaling cannot be figured out in theory only. The factors have to be defined, evaluated and tuned iteratively to get an optimum of intuitiveness.

An algorithm for the system to determine the pivot in SIH mode has to be implemented in order to set the pivot to the object closest to the user's interaction. The pivot has to be made visible to the user with appropriate measures. Users should test this.

Evaluate New Hardware

New hardware for the SGD should be evaluated because of the troubles stated earlier. The following characteristics are recommended:

- Capacitive detection technology
- Precise detection of multi-touch gestures
- Capable of detecting more than two-finger gestures

Furthermore screen size and position (vertical or horizontal) could influence the user's behavior whether operating with one or with both hands.

Help and Assistance

The above-mentioned functions have to be implemented and evaluated, such as:

- Key instructions and help
- Context information
- Implementing landmarks and Landscape
- Improve visual design

Widget Version

If widgets are to be used for the SGD, the improved widget version should be developed further. In addition to that the following options could be investigated:

- Activation of functions by toggling them on and off similar to CAD tools
- Move elevation function from the widget to a separate sidebar
- Design a widget for left handers

Further Investigations

There are some topics that have not been addressed in this work but would be interesting to look at:

According to the sponsors the SGD should attract people waiting in the lobby and invite them to explore the smart grid setup in the Segelhof campus. It could be evaluated in a separate study how the attractiveness of the SGD had to be increased.

In the design emphasis of chapter 3.6 the aspect “engaging” has been put to high importance. This was defined because of the requirements already mentioned above. The project team decided not to focus on this and not to evaluate it. It would be interesting to figure out what factors make the SGD more engaging and how this aspect could be evaluated.

Because of the wide-angle perspective used with SGD, some users thought that they were rotating the model while panning left or right. It could be analyzed what focal width is best for the user.

Some cited studies in the theoretical part of this work mention that systems allowing a higher number of possible touch-points would support more natural gestures. Hence this would have a positive effect on the intuitiveness. It could be investigated in a further study, what influence multi-touch gestures with more than two fingers have in the context of SGD.

5 A Critical Look Back on Scientific Approach and Methodology

The following chapters reflect the used HCI methods and illustrate why these methods were chosen, what worked well and what could have been done better. The results are then discussed in terms of scientific aspects. Lastly personal experiences are presented as well as what the project team has learned.

5.1 HCI Methods

5.1.1 Research of Current Literature

Finding appropriate literature covering the 3D navigation on multi-touch-screens like the one for SGD was a challenging task. First we were confronted with a very broad field of researches that dealt with virtual environments and 3D interaction. We mainly found studies covering specific and narrowly focused subjects. Nevertheless this gave us some basic knowledge about the 3D interaction topics in order to plan the upcoming usability evaluation of the SGD. A further effort was necessary though to find more literature that addresses SGD specific problems. Finally we were able to put bits and pieces together that not only helped us to understand the context theoretically but also to develop design proposals later.

After the first approach we got somewhat frustrated searching through the literature without overwhelming success. There was no literature to be found that covered the subjects close to the ones we faced with SGD. Discussions in the coach meetings encouraged us to put some extra effort browsing through literature databases again.

Looking back on this, we conclude that an early and thorough literature research is essential for starting with such a project. For a project that is in the research field, literature research should start even before agreeing the thesis definition with the university and the sponsor. We suggest scanning the literature databases systematically with a broad focus first and narrow it down later. This could be done individually in division of work among the project team. A regular conversation about the findings and to align the search words is advised. After having collected interesting literature they have to be judged for their relevance and filtered out.

5.1.2 Requirements Engineering

As described in chapter 3.1.1 requirements engineering could not be conducted like in regular user centered design (UCD) projects because there were neither real users nor real tasks. Therefore we had to think of alternatives to get the user needs collected. Gathering first characteristics of users from interviewing stakeholders who knew about the idea of the SGD is still in line with UCD processes. But it seems to be unusual taking user expectations out of a usability evaluation. We decided to ask participants in the first usability evaluation about their expectations for the SGD. Even though Cooper *et al.* (2007, p. 143) state that usability testing is not the same as user research and research must occur before ideation they also say that for some practitioners, tests can include research activities. We think this approach contributed many additional useful characteristics to the user specification.

Goodwin (2009) describes a comprehensive process for modeling personas. In contrary to Goodwin we used a straightforward procedure for modeling three provisional personas. After gathering all possible characteristics of users in a spreadsheet we used the same as a morphologic box. We believe that this technique is appropriate, in such projects like ours where only vague requirements are known and no real users exist yet.

5.1.3 Evaluation of Initial Implementation

The first usability evaluation should reveal the most serious problems, besides the above-mentioned collection of user expectations. We therefore decided to conduct a formative usability test. According to Cooper *et al.* (2007) usability tests are (among others) good to identify major problems with the interaction framework. We did not use measurable metrics like *time-to-task-completion* or *number-of-clicks*. Mayhew (1999, p. 230) also suggests that timing data is not typically collected in early evaluation tasks (conceptual model evaluation).

By passing through the same test sequences twice we wanted to find out how easy the functions of the widget could be learned. The results shown in *Table 3-3* are discussable because not every function was requested to carry out during the tests. That is why some participants struggled so hard getting along with the system that we eventually stopped the test sequence and went on to the next. The idea was not to frustrate participants. This should be considered in future tests especially when comparable results are needed.

The ISO standard questionnaire developed by Pruemper (1993) is designed to inquire the seven usability criteria based on ISO standard 9241/110. This questionnaire is useful to evaluate the design and interaction of software. The problem was that some questions could not be answered because they were not applicable to the SGD. This might have questioned the credibility of the questionnaire to some extent. Even though the results cannot be taken as hard figures, they show a tendency of improvements or worsening of the compared SGD versions.

The data analyzing process as described in chapter 3.1.2 “Analysis” took a while. But looking back, we would do it the same way except for making sure that everybody in the team takes part in all workshops. This would prevent discussions later to gain a common view about results and interpretation of findings.

5.1.4 Developments of Solutions and Design Process

We had a lot of intensive discussions about the possible solutions first, which were based on literature and on findings of the usability evaluation. After that the design process was quite straightforward in terms of the basic ideas. The hard work was putting together the usability issues and user expectations with the basic solutions. If we had more time we would have put more effort on details like widget design and gesture development. This could have been done in several iterations.

For a while the sponsor did not commit us to have resources available for implementing our design proposals. After discussing the final proposals with the sponsor he agreed to start developing the software. Since one team member works with ABB, close cooperation between the project team and the software developer was possible. This advantage not only helped to clarify questions fast but also allowed us to do quick tests of some software parts.

5.1.5 Evaluation of Proposed Solutions

The second evaluation was similar to the first. Based on the experiences made in the first one, the tasks for the usability test were written more distinctly and enriched with print screens of the destination. This time we also made sure that every participant went through each task in order to have comparable data. The interview guideline was written in a stricter way because contrary to the first evaluation we asked for statements about certain topics.

Because of hardware deficiency the second usability evaluation had to be carried out on a different multi-touch-screen, which was smaller but with the same sensor technology. The screen used was set on a desktop therefore the participants were sitting instead of standing as they were in the first usability evaluation. The different working position may impact the ergonomics hence influence the test results. Nevertheless we focused more on comparing the two new software versions and not so much the original with the new ones.

In a *within-subjects design* where all participants conduct both test runs (refer to chapter 3.1.4 section “Usability Evaluation 2”), there is an inherent bias on the test results, the so called *carry-over-effect*. Altering the test sequences can eliminate this. In order to check if there are still some factors influencing the results the interview answers were analyzed carefully with the following finding: The test sequence (A/B or B/A) had only little influence on the answers of interviewees. On the one hand a tendency could be observed with question 2 and 4, where participants preferred the first version they walked through (*primacy effect*). On the other hand participants preferred the last solution in question 9 (*recency effect*).

5.2 Scientific Aspects of the Results

The emphasis of this project was to evaluate and improve the 3D interaction of the SGD. Therefore a practical approach with applied UCD methods was the main focus. In the same time we researched the state of knowledge by studying the available corresponding literature. We formulated three theses, which we tried to falsify firstly by making conclusions of the theoretical research and secondly by the findings of the usability evaluations. This is one scientific aspect of our work. Since the usability evaluations mainly produced qualitative data, the statements cannot be affirmed with hard figures. No metrical data that withstand a statistical prove of significance could be collected.

Our pretention was to apply the UCD methods within standardized procedures, which we see as the second scientific aspect. This was achieved by clear tasks, conducting interviews following guidelines and consistent processing of the usability evaluations and their analysis. Even though the validity of results cannot be proved by statistical methods, we think that the findings are valid due to the fact that we took great care in all steps throughout the project.

The following issues regarding scientific quality criteria have to be mentioned though:

A bias can be assumed in the second evaluation comparing test run A and B. The symbols of the widget might have given users the positive feeling of being helped or guided although they struggled on how to use the functions correctly. This might explain why test run A was rated much better in the ISO standard questionnaire than test run B. Furthermore the system ran much more fluently with version A and had less technical issues like a jumping viewpoint.

The modeling of personas was rather based on assumptions derived from interviews of sponsors and participants of the first evaluation than on real users. While tasks are usually generated from contextual inquiries we had to deduce them from statements of sponsors in the interviews.

One of the most serious issues regarding scientific aspects was that we changed more than one factor at the same time while comparing both solutions with their widget, gestures and metaphors. This makes it difficult if not impossible to find the causality of improvements. If this were a pure scientific study, each software version with a single changed variable should have been subjected to each participant. This would have extended the tests in a way that would not be reasonable for participants.

There is another bias that has to be mentioned. The second usability evaluation was done on different hardware. As explained earlier there were problems running the new software on the original SGD multi-touch-display. That is why we had to change the hardware, which was faster and more reliable.

5.3 Lessons Learned

UCD Methodology

Looking back to the project, we think that the used UCD method worked out quite well. We believe that usability testing as a means of evaluation revealed relevant findings with which we were able to suggest important improvements or facts for further investigations. Formative usability tests are great in early design phases like we used for our first evaluation where qualitative data is more important than measureable variables. Doing summative usability tests like in our second evaluation, standardized processes should be followed in order to get reliable data to compare different solutions. Metrics, such as *time-to-task-completion* would help to rate each solution better. As for summative usability testing, it should be reflected to give participants a short time for getting themselves familiar with the system before starting the tests.

Interviewing stakeholders for inquiring requirements worked well. One interview partner was very talkative and eager to talk about things that were not really asked for. Therefore the interviewer should actively guide the interviews so that the targets are not missed. Interviewing participants after the usability tests was different. The focus was on users' expectations and impressions (first evaluation) as well as opinions and preferences (second evaluation). Especially foreign speaking people sometimes did not understand the questions and did not get to the point. In this case the interviewer has to ask the question again in other words not to frustrate the participant. When asking participants about their opinion we often noticed that they answered more positive than what we concluded from observation during the tests. We think that the participants did not want to embarrass us but appreciate what we have done. Most of the participants were colleagues either from the software developer or from one of the project team members.

Audio and video recording is key for post-processing data. During the usability tests it is almost not possible to catch all issues. Taking notes right away in the tests is useful though but recording video and voice takes away pressure from the observer knowing that certain parts can be reviewed. The same is true with interviews.

Project Organization

A timeline has been defined at the start of this project, which could be followed quite close except for the following phases. We had to postpone the second evaluation by two weeks because the implementation phase took longer than planned. The writing process also took some weeks longer. But thanks to time buffers this was no problem at the end.

Job roles were not strictly defined among the team members. The project team rather organized itself in a natural way. The job leader was mostly allocated by discussions according to skills, interest and available time. One of the team members was employed at the sponsors company. While this was an advantage most of the time there is also a risk coming along with it. The colleague working for ABB did most of organizing, like arranging interviews, recruiting test participants and supporting the implementation process. This burdened him with additional responsibilities and extra work.

Collaboration

Different collaboration tools helped the team to work remotely. While Google Docs was used to collaborate on documents, data like pictures, voice and video files were stored on Dropbox. The blogging platform WordPress helped to share and comment ideas as well as giving space for storing intermediate findings and conclusions.

Since every team member has its own professional background, hence different skills, the team complemented one another gainfully. At the same time this diversity was challenging. There were some serious discussions in the team about root causes of problems and possible solutions, but time just ran out before consensus could be found. This was occasionally frustrating.

General Experiences

As already mentioned, this master thesis subject was in the research field. This was a critical fact because of the vagueness that comes with it. There were no real users nor were there tasks that could have been inquired. Therefore many of the requirements had to be derived from the sponsor's vision or they simply had to be defined by the project team. In this case requirement engineering was much like marked research. Furthermore standard UCD processes are not effective with such a project and UCD methods cannot be applied one-to-one.

Looking back it would have been better to even more narrow down the scope. But saying this in retrospective is easy, because in our case the most interesting topics evolved during the evaluation.

There was a constant learning curve during the whole project. For example, the project team first favored a paradigm change from SIH to EIH concluded from the literature. After the first evaluation the team recognized other factors that were important for improvements.

6 Glossary

2D Two-Dimension(al)

3D Three-Dimension(al)

3Space bat is a 6-DOF input device that allows positioning and rotation manipulations along all axes

Augmented reality (AR) is a real-world environment which is enhanced (augmented) with virtual objects or information such as head-up-displays used in modern military air crafts.

Between-subjects design is an experiment design used in scientific researches, where every participant is only subjected to a single test-version

Carry-over-effect is an effect seen in scientific experiments, where every participant is subjected to more than one test-version (*within-subjects design*) and therefore test A could influence the results of test B

CRC ABB's Corporate Research Center at Dättwil, Switzerland

Cross-case-analysis is an analyzing method for qualitative data like interviews, where cases are compared and analyzed for similarities or differences

Degrees of freedom (DOF) *Degree of Freedom* (refer to chapter 2.2.3)

Eye-ball-in-hand (EIH) is a virtual environment metaphor

Freedom of control describes to which degree navigation is supported, guided, constrained by the system

Hallway test consists of a number of micro usability tests in a sequence during the design process, which are conducted spontaneously with colleagues in order to eliminate many small stepping stones before doing a complete usability test

Immersive Virtual Environments are VE in the common sense but meaning the degree of how users feel part of such a system. A good example would be the Holodeck as seen in the Star-Treck series or flight simulators.

ISO standard questionnaire evaluates the usability of software with graphical user interfaces

Isometric control measures forces applied to a device

Isomorphic control measures position or motions of the users' hand/finger

(3D) Model is used as a synonym of Virtual Environment

Pivot is the anchor point or point of control, e.g. the center of scale or rotation

Polhemus is an input device (tracker) that tracks position and rotation of objects that can be used to translate to objects in a VE

Power-of-ten is used as a term for a scaling factor using 10^1 , 10^2 , 10^3 , 10^4 ... 10^9 ...

Primacy effect is a cognitive bias where information presented first in a series is recalled better than information presented later

Project team consists of the MAS students Egli, Hirst, Sacher

Recency effect is a cognitive bias where information presented last in a series is recalled better than information presented before

Semi-structured interview is an interview technique where interviewees are asked questions according to a guideline that only works as a thread. The interviewer is free to leave some questions out or ask additional ones

Scene-in-hand (SIH) is a virtual environment metaphor

SGD Smart Grid Demonstrator

SGD UI Smart Grid Demonstrator User Interface

Structured interview is an interview technique where every interviewee is asked exactly the same questions according to a strict guideline

UI User Interface

UCD User Centered Design

Virtual Environment (VE) is a synthetic, spatial (usually 3D) world seen from a first-person point of view. The VE is under the real-time control of the user.

Virtual Reality (VR) is a synonymous of virtual environment (*VE*)

Viewpoint is the point of where the current scene (usually 3D) is taken from, hence the position and angle of the camera.

Viewport is a part of the screen-output where something gets visualized

Within-subjects design is an experiment design used in scientific researches, where every single participant is subjected to every test-version

World-in-hand is a synonym of *scene-in-hand*

Widget see chapter 2.2.2

Way-finding the cognition of ones' position and surrounding

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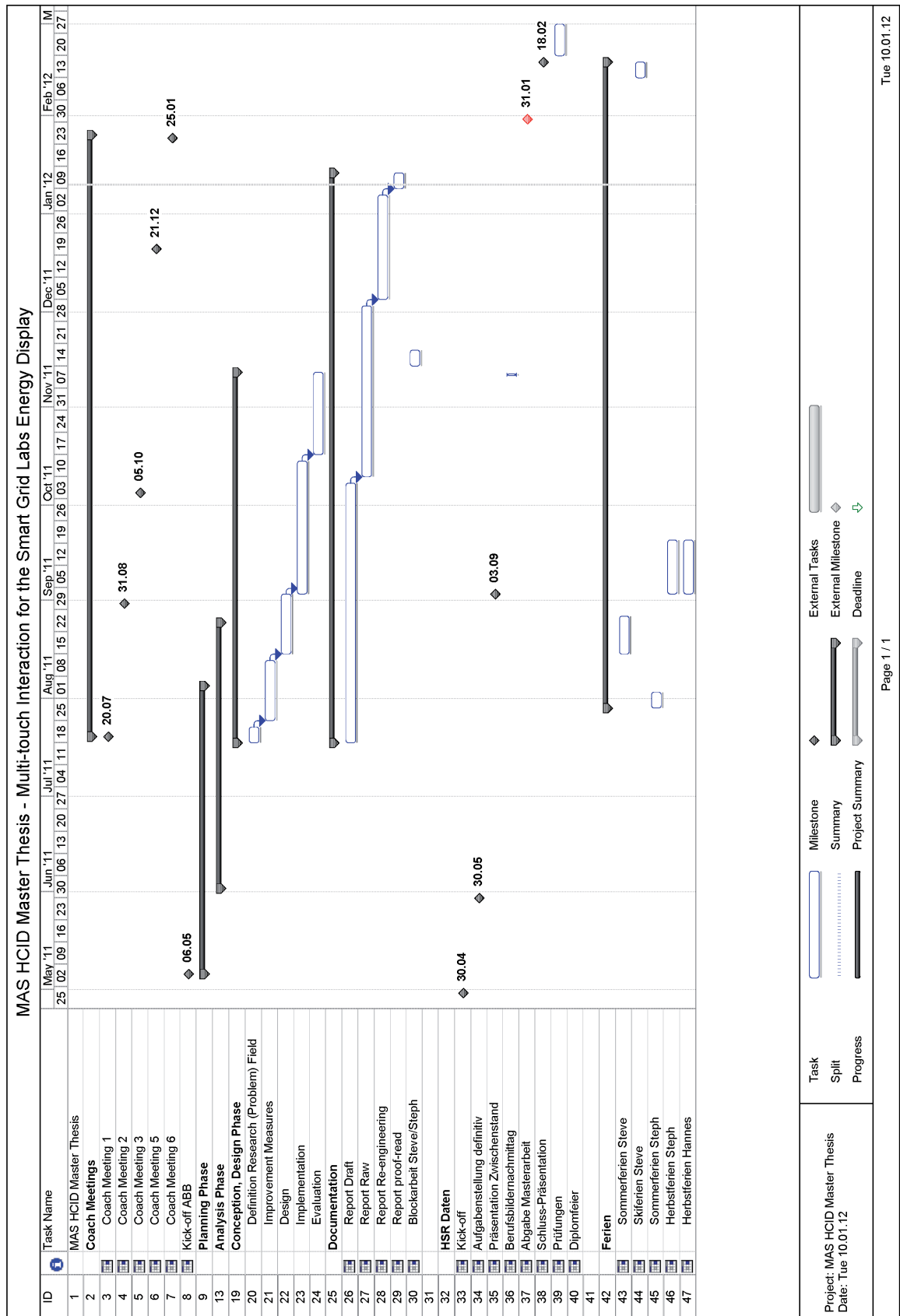
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Addendum 2. Requirements Analysis - Characteristics of Persona (Morphological Box)

Category	Parameter	Characteristics			
Demography	gender	female	male		
	age	< 16	16 - 65	> 65	
	profession	sales people [mn, sa]	researcher [mn]	energy expert [mn]	reseller [mn, sa]
	user type	active user [mn]	casual user [mn]	non user (Families, Technorama visitors, children) [mn]	private user [ms]
	user role	visitor [mn]	professional [mn]		
User skills	frequency of usage	regularly [ul]	occasionally [ul]	seldom [ul, mn]	
	familiar with touchscreens	yes [ul]	no [ul]		
	Software skills	non [mn]	professional (8) [ul]		
User goals	aim	curiousness [mn]	exploring SGD [mn]	learning smart grid [mn]	demonstrate smart grid [mn]
	task	give demonstration [mn]	exploration [mn]	get demonstration [mn]	analyzing data (non szenario) [mn]
	fields of interessts	smart grid [mn]	energy production, distribution, consumption [mn]	facility automation [mn]	renewable energy [mn]
	motivation	find out what data are displayed [mn]	find out what is it all about [mn]	to see how much current actually my computer is consuming [mn]	to see how much current actually this building is consuming [mn]
	way of interaction	clicking around [mn]	streight forward [mn]		
	dislike	spend too much time [mn]	getting annoyed [mn]	reading too much texts [mn]	
	expectations (interaction)	System should invite me [mn]	intuitiv [ul]	like an iPhone [ul]	uniform patterns [ul]
	expectation (behavior)	immediate interaction [mn]	GUI moves fluently [mn]	precise reaction [mn]	
	preferred installation	wall mount [mn]	portable, at customer [mn]		
	fears	manipulating 3D model [ul]	afraid of playing around [sa]		
	wishes	description on the buildings [ul]	landmarks [ul]	different colours [ul]	key instructions [ul]
Quotations					

Category	Parameter				
Demography	gender				
	age				
	profession	any [mn]	decision maker [mn]	energy consultant [mn]	software engineer (non user) [mn]
	user type	industrial user [ms]			
	user role				
User skills	frequency of usage				
	familiar with touchscreens				
	Software skills				
User goals	aim				
	task	get information fast and efficiently [ms]			
	fields of interessts				
	motivation				
	way of interaction				
	dislike				
	expectations (interaction)				
	expectation (behavior)				
	preferred installation				
	fears				
	wishes	nice GUI [ms]			
Quotations					

Category	Parameter			
Demography	gender			
	age			
	profession	post graduate students [sa]	public officials [sa]	politicians [sa]
	user type			
	user role			
User skills	frequency of usage			
	familiar with touchscreens			
	Software skills			
User goals	aim			
	task			
	fields of interessts			
	motivation			
	way of interaction			
	dislike			
	expectations (interaction)			
	expectation (behavior)			
	preferred installation			
	fears			
	wishes			
Quotations				

References	[ul] = Usability Lab
	[mn] = Interview M. Naef, GUI Developer
	[ms] = Interview M. Savia, Productmanager ABB Facilities
	[sa] = Interview S. Andermahr, Communication
	primary persona
	secondary persona
	non persona

Provisional Primary Persona

Name: Joe Primus
Role: Explorer
Age: 32
Profession: Energy Consultant

Profile:

Joe works as an energy consultant with the environmental department of the city of Zurich. Before he applied for his job, he just finished his master degree in sustainable development at the University of Basel. In his job, he mainly advises colleagues of the energy department as well as architects or occasional customers who want to build their own house. In the last few months, Joe has heard a lot about smart grid. He is now eager to learn more about that trendsetting technology. Therefore he has an appointment with the product manager of the smart grid project at the Corporate Research Center (CRC ABB).

Goals:

While he is waiting for the product manager in the lobby at the CRC ABB, he notices a big display which is mounted on the wall nearby the lounge. He has never seen something like this before and soon that monitor attracts his attention. While Joe watches the short presentation about the smart grid and the smart grid demonstrator itself, he gets curious of what this is all about. After the presentation is finished a cool looking three-dimensional model of the CRC campus is displayed. From the animated instructions Joe finds out that he may play with the model and even find out more information about the smart grid test installation at CRC. By this moment, Joe is eager to learn more about smart grid. He is also interested in the energy production, distribution and consumption data on the campus.

Typical Action:

While he is touching the display, a nice looking navigation widget appears that makes it easy for him to explore the smart grid demonstrator. Joe is just tapping around a bit and soon he gets comfortable with the way he can interact and manipulate the three-dimensional campus model. The graphical user interface lets him move the model up and down, zoom in to a certain building and zoom out again. In order to look at the solar-panel that is mounted on the roof top of one building on the other side of the campus, he rotates the model and elevates his viewpoint. He easily gets information about the actual power production of the panels. The navigation of the model moves fluently and reacts immediately to his gestures. While Joe is exploring other energy-related information on the campus he soon gets a good overview of the smart grid matters. Some more ideas on using smart grid and adopting it to other areas of use come to his mind.

Expectations:

When Joe first noticed the possibility to interact the 3D model he thought of getting annoyed by struggling with some complex interaction functions. But thanks to the short key instructions and the intuitive navigation widget he was absorbed by the nicely designed graphical interface in no time. Furthermore because of uniform interaction patterns he was able to explore the campus without hassle. Having some landmarks on the model would help for orientation.

Provisional Secondary Persona

Name: Sam
Role: Demonstrator
Age: 42
Profession: Sales Representative

Profile:

Sam is a sales representative who works for an international company that produces and installs power plants. In the last few years Sam was engaged in the smart grid subject quite a lot. Because of his deep knowledge of the material, he regularly gives professional demonstrations of the smart grid to visitors. His audience includes energy experts, public officials like politicians and decision makers as well as groups of researchers and post graduate students.

Goals:

The demonstration for groups is rather standardized. Therefore Sam wants to have a graphical interface that runs smoothly and whose way of navigation is straight-forward. This lets him concentrate on the subject, not being absorbed by the system. On the other hand, Sam likes to demonstrate smart grid to individuals in a conversational manor. Individuals often have certain questions, so Sam wants to get the desired information fast and efficiently. A graphical user interface that reacts precisely is important for him because he does not like fiddling around with the navigation until he gets to the desired view.

Typical Action:

(eventually describe a typical demonstration)

Expectations:

He expects an interface that is easy to use. He does not like to read too much text before finding out how it works.

Provisional Non Persona

Name: Fred
Role: Software Engineer
Age: 32
Profession: Software Engineer

Profile:

Fred is a software engineer working for a national power distribution company. In his job he develops software to display statistical charts of the energy flows within the power grid. Since smart grid is said to be an emerging technology in his company, Fred has been assigned to the expert team that is developing smart grid.

Goals:

Fred wants to analyze energy flow data that are sampled throughout the national transmission lines. This data will then be calculated and visualized using trend charts as well as heat maps.

Expectations:

Since Fred has been working in a complex technical field for a long time he always wanted to show his family what his job is about. Therefore he plans to visit the Technorama in Winterthur. There he expects to find a display that would demonstrate the smart grid technology to his son in a playful way.

Introduction

Time:

Min. 0

- We test the system – not you
- Part 1 - Interacting with the system
- Part 2 - Interview
- Time 30 to 40 minutes

Interacting with the System

Time:

- Min. 5 Phase 1 – Solving tasks **without introduction** to check how intuitive the system is
- Min. 12 Introduction of navigation
- Min. 15 Phase 2 – Solving tasks **with introduction** to check learnability of the system

Task 1 (zoom)

You want to see some details of a building and want to look at it more closely.
Please choose a building and zoom into it.

Task 2 (pan)

Please move to the right and left to see other parts of the building.

Task 3 (rotate)

Now you want to see the back of the building. (You might want to zoom out a little)

Task 4 (double-tap)

Additional information can be found within the model. Please bring forward such information.

Task 5 (pitch, „reset view“, orientation)

Please navigate to the main entrance of the building. Please position yourself as if you would stand there in real life.

Task 6 (elevation)

Please try to navigate to the 2nd floor of a building section.

Test participant

Age:

Gender:

Job:

Experiences with Smart Grid Demonstrator:

Application

How did you feel during the exercises?

- What was difficult?
- What was easy?

What is your general impression of this application?

- What is positive?
- What is negative?

Were you always able to orientate yourself, where you “stayed” in the 3D graphics?

- Where did you get stuck?

What’s your impression about the user guidance?

- Was the navigation understandable to you?

Were you pleased by the interaction? How?

What do you think about the design?

Would you have used or explored this application on your own?

How long would you spend to “play around”?

Would you use this application?

- Have you missed something? What function would you like to have?
- What would have to be changed / improve at most?

Exercises

Have the exercises been realistic?

- Have they been feasible?
- What would you change?

What exercises were missing?

Addendum 6. Usability Evaluation 1- Protocol Example

Observer	Steph Egli		
Test Candidate	#2		
Date	20.06.2011 09:00-10:00		
General observation	right-handed used mainly one hand for navigation centered his finger generally on the middle of an object usually alternated the left or right forefinger for holding the widget in 1st phase used only one hand, in 2nd phase both hands		
mm:ss	Task	Observation (What? Why? How?)	Type
01:18	1a	uses two finger to start navigating	gesture
01:19		zoom: with 2 fingers; contract finger equals zoom-in	gesture
01:20		immediately after trying to zoom he presses the 3D reset button, several times	behavior
01:24		presses the 2D reset button, 2 times	behavior
01:25		zoom: with 2 fingers; contract finger equals zoom-in	gesture
01:27		widget pops-up 1st time, he does not pay attention to it	behavior
01:32		presses the 2D reset button, 2 times	behavior
01:36		presses the 2D reset button, 2 times	behavior
		repeats this behavior several times	behavior
01:58		tips on trakt F to zoom in, info flag pops-up, he does not pay attention to that, immediately after he presses the 3D reset button	gesture
		repeats this behavior with alternating "contracting finger" and "tipping" the object several times	behavior
02:22		"I don't understand the meaning of these icons (reset buttons), because when I click something, I should get some text what it means, this is something I could not figure out. I would like to know what these icons mean"	comment
02:55	3a	uses two finger to start navigating (around 30° diagonal)	gesture
02:27		presses the 2D reset button, 2 times	behavior
		repeats this behavior with using the 2D and 3D reset button from time to time	behavior
02:57		puts forefinger on the object (building) and tries to move it left with the thumb	gesture
03:06		uses widget the first time, holds his thumb in the middle of the widget	behavior
03:08		pan: moves the object left with the thumb, but still tries to move the object with the forefinger right	gesture
03:13		looses control again	
		repeats this behavior with alternating "contracting finger" and "tipping" the object several times, and using 2D and 3D reset button from time to time	behavior
03:34		"I see an icon but it doesn't appear again" (he probably meant the widget, which should appear after pressing the reset button)	comment
03:59	2a	rotate: starts with pressing the 2D reset button, then tips the thumb on the object and rotates with the forefinger	gesture
		repeats this behavior using 2D and 3D reset button from time to time. Sometimes changes the order and tips the forefinger on the object and rotates with the thumb	behavior
04:30		rotate: tips the forefinger on the object and uses the pitch button of the widget with middle finger, then releases the forefinger and makes a large circle with the middle finger -> view pitches	gesture
04:36		"I don't know, I see something but..."	comment
		repeats this behavior using 2D and 3D reset button from time to time. Sometimes changes the order and tips the forefinger on the object and rotates with the thumb	behavior
04:46		rotate: tips the middle-finger on the object and uses the rotate button of the widget with forefinger, then releases the middle finger and makes a circle within the widget	gesture
05:20	6a	tips on "Display lights"	gesture
05:28		zoom: tries to zoom into trakt G by using same gestures and behavior like above, alternating pressing the reset button. Tries out several "View Buttons" on the left navigation pane	behavior
06:01		"So I cannot do it..."	comment

mm:ss	Task	Observation (What? Why? How?)	Type
06:34	4a	searches for the main entrance, hesitates to press the reset button	behavior
06:40		Tips the "View Button" "Site overview"	behavior
06:45		"From there I cannot identify where the entrance is"	comment
06:47		tips the 3D reset button	behavior
		zooming and panning: tries like above, alternating tipping the reset buttons	behavior
07:00		tips the 2D reset button	behavior
07:05		pan: moves the "Gartenhaus" object up by holding the forefinger in the middle of the widget and panning (up)	gesture
07:12		tips on the "Gartenhaus" object (to try to zoom-in)	gesture
10:07	1b	zoom: tips with the forefinger in the middle of the campus, and with the left-hand forefinger on the top-right of the "zoom-ring", then releases the right-hand and moves the left-hand forefinger to the top right-edge of the monitor	gesture
10:22		"But at least when I click here it should say that it zoom-in or zoom-out. I mean some help message I'd need." "When I press here (the widget pops-up, I don't know what these arrows mean"	comment
		He expected help message when tipping the reset buttons	
11:24	3b	tips with the left-hand forefinger, till the widget pops-up	gesture
11:27		tips with the right-hand forefinger into the middle of the widget (in parallel) and releases the left-hand	gesture
11:30		pitch: wants to pitch by tipping the left forefinger on the pitch button, makes more rotate gesture, struggles with touchscreen reaction (seems to interfere with the rest of left fingers)	gesture
11:58		wants to close the pop-up flag (of trakt G), which overlays on the pitch and rotate buttons, struggles with the small "close X"	behavior
12:06		zoom: left forefinger holds widget, with right forefinger he zooms on top left of the widget (ring)	gesture
12:19		pan: changes several times from left forefinger to right forefinger	gesture
12:34	2b	rotate: interferes with left hand fingers	gesture
12:40		rotate: tips with left forefinger, till the widget pops-up, then tips rotate button with right forefinger, starts to rotate and releases left hand	gesture
13:10	6b	zoom: tips with the right forefinger and zooms with left finger towards top right of the monitor and releases right hand	gesture
13:21		tips a KNX Sensor object in the G trakt	gesture
		searches for information about the object in the 3D view and on the right pane	behavior
13:40		"For me everything looks the same, it says it's a sensor but I don't see a sensor here, it's (the flag) pointing to a block" " It needs to be differentiated at least by colour"	comment
14:15	4b	zoom: tips with the right forefinger to the "Gartenhaus" object and zooms with the right forefinger	gesture
14:19		rotate: holds the right forefinger in the middle of the widget and starts with the left forefinger to rotate towards the middle of the widget, releases the right hand	gesture
14:22		the widget disappears (incidentally?), then he immediately tips the 3D reset button	behavior
14:25		tips the "Gartenhaus" object (which is static), the view zooms out automatically	behavior
14:28		tips the 3D reset button	behavior
14:32		rotate: tips with right forefinger, till the widget pops-up, tries to rotate with the left forefinger and interferes with the left-hand fingers -> view zooms out autom.	gesture
15:22		troubles with reset view autom. by touching static objects	behavior
15:35		"I'm doing something like zooming-out, just pressing it brings back the view. Didn't expect that. I'd need to be very precise."	comment

Date	20.06.2011 09:00-10:00
Test participant:	#2
Age:	34
Gender:	m, right hander
Job:	Scientist in Software Engineering.
Pre-Knowledge:	Has no experience with SGD, never used it before. He has just seen it from a distance.

Testimonial

The first part was hard to manage for me. The second part after instruction was easier. Although the interface looks good at first sight I am not able to use it without help or instruction. Furthermore it is not yet complete. I lost the orientation from time to time. The pop up messages did not help much. It would be good if they were for help and orientation. Regarding the user guidance, I did not understand what the function was of the icon on the lower right corner (view reset). I thought that this would activate the widget or would be linked with the zoom somehow. I like the "single wheel" (the widget) as such but I usually lost control of the buttons.

The design looks good even though I missed colors, which would help to distinguish different things. Besides, I missed the one-to-one information with the sensors. I do not think that 3D navigation is necessary. I only want to get information about the sensors.

I did not check out the SGD in the past because I had no interest in it and I did not know what to search for. But I knew that one can interact with it. Maybe I would play with it for ten minutes more in the future.

I could not differentiate between sensors and objects. Adding some different colors would help to better distinguish them. The widget is not clear to me and the green coloring of the buttons did not help me to understand their functionality. Besides that, the navigation buttons on the left confused me. Jumping to a certain building by pressing a button could be helpful. On the other hand I did not miss any more functions for navigation. When I zoomed in and touched an object, the view was reset unexpectedly. I would change this behavior.

The exercises were realistic and feasible. I would not have changed anything on the test.

Observation

He starts navigation with two fingers almost from the start. The gestures he tries are similar to the zoom on an iPad. He tries several times and immediately after trying to zoom he presses the reset buttons on the bottom right. He expected a relation between the reset buttons and popping up of the widget, and misses some help text for these reset buttons. This behavior draws through the whole first phase (without giving instructions). To summarize, without explanations he did not understand the functions, he just tried several gestures he might have known from smart-phones. Pan and pitch he found out more accidentally, but he could not really reproduce them. After explanations he still used both hands for the widget most of the time, interfering several times with his other fingers. Usually he called the widget with a forefinger and e.g. zooms by intersecting with the other hand.

He generally expects help texts for functions and navigation as well as a more sophisticated graphics, at least different coloring for different objects. On the other hand he rather ignored widget symbols and pop-up flags.

His gestures and interactions are rather fast and hounded as well as rather imprecise, such that the system is always a step behind and does not react as he expects.

Conclusion:

He never really had control over the system. He seemed to be frustrated because the system usually did not react as he expected and he never really could solve the exercises. He was unable to learn gestures as the system interprets his gestures wrongly. He is not the type who learns visually, he needs and expects help text explaining him how the gestures and the system work.

Using both fingers for the widget he usually struggled with gesture motions and interfering finger, using only one finger worked better.

Addendum 8. Usability Evaluation 1 - Issues

ID	Problem	Case Reference	Occurrence	Priority	Report	Usability Category	Affected Component
U19	Irritating info pop-up	1-9, 2-2, 2-3, 2-8, 2-9	>5	1	x	Unexpected behavior	Pop-up
U18	Zoom jump	1-1, 1-4, 1-8, 2-1	>4	1	x	Unexpected behavior	System
U21	Pop-up window opens unexpectedly	1-6	>1	1		Unexpected behavior	Pop-up
U01	Wrong control chosen	1-2, 1-6, 1-5, 2-5, 2-9	6	1	x	Affordance	Widget Control
U22	Zoom gesture	1-1 to 1-6	6	1		Expectations	Widget Control
U09	Widget jumped	1-1, 1-3, 1-6, 1-8, 2-3	4	1	x	System Failure	Widget
U23	Pan gesture	1-1, 1-3, 1-4	3	2		Expectations	Widget Control
U04	"widget don't help much"	1-1, 1-2	2	1		Affordance	Widget
U11	Widget not appearing	1-5, 2-6	2	1	x	System Failure	Widget
U14	Feedback of system is problematic	1-1, 1-4	2	1		System Failure	System
U25	Two-finger gestures expected	1-6, 1-9	2	1	x	Expectations	Widget Control
U30	Model jump	2-1, 2-3	2	1	x	Unexpected behavior	System
U34	Elevation in wrong direction	2-4, 2-8	2	1	x	Mental Model	Model
U15	Accuracy of touchscreen	1-6	2	2		System Failure	System
U24	Rotation gesture	1-9, 1-4	2	2		Expectations	Widget Control
U26	Widget does not stay on	1-5, 1-9	2	2		Expectations	Widget
U27	How to call up widget	1-2, 1-9	2	2		Expectations	Widget
U02	Doesn't understand reset icons	1-2	1	1	x	Affordance	Reset Button
U07	Issue with mental model	1-3	1	1		Mental Model	Model
U08	Mental model; first person view	1-3	1	1	x	Mental Model	Model
U10	Unexpected widget behavior	1-4	1	1		System Failure	Widget
U12	Rotate, but other function activ	1-4	1	1		System Failure	Widget Control
U13	Double-tap does not respond	1-5	1	1	x	System Failure	System
U20	Difficulties with learning gestures	1-3	1	1	x	Unexpected behavior	Widget Control
U28	It reacts too slow	2-3	1	1	x	Expectations	System
U31	Info pop-up overlaps widget	2-6	1	1	x	Unexpected behavior	Pop-up
U33	Elevation direction	2-6	1	1		Mental Model	Model
U03	Symbols on widget ignored	1-4	1	2		Affordance	Widget Control
U05	Widget ignored	1-2	1	2		Affordance	Widget
U06	Tipping on pitch icon	1-5	1	2		Affordance	Widget Control
U16	View reset	1-4	1	2		Unexpected behavior	System
U17	Sudden view reset	1-3	1	2		Unexpected behavior	System
U29	Rotate/pitch combination (hemisphere) is maybe more intuitive	2-8	1	2		Expectations	Widget Control
U32	Struggles with system/widget	2-2	1	2		Problems using widget	Widget
U35	Elevation gesture	2-6	1	2		Affordance	Widget Control
U36	Pitch icon	2-5	1	2		Affordance	Widget Control

ID	Remarks	proposed solution
U19	Pop-ups overlay widget or confuse user	Show/Hide button for all pop-ups on left Nav Pane or show pop-up (or info flag) of an object after touching the object with some delay (-> condition: remove widget), or in context menu Evtl. show pop-ups only at going below a certain distance to the object
U18		fix the bug or reduce/limit gain factor when selecting a far object
U21	Happend several times (pop-up window -> info "flags" for selected object)	refer to U19
U01		use distinct icons for controls position controls more exposed
U22	iPhone gesture was expected	refer to E09
U09		bug must be fixed! use other touchscreen technology (resistive or capacitive) to prevent "interfering fingers"
U23	iPhone gesture was expected	refer to E09
U04		refer to E09
U11	Finger bent in case 1-5	refer to U09
U14	- Especially when zooming, the GUI reacts in unexpected ways several times - The GUI jumps around frequently. It is not clear, whether this is related to hardware precision problems or to lacking of error tolerance in software	refer to U18
U25		refer to E09
U30		jump
U34		refer to U07
U15	Citation 1: "it doesn't click there, where I wanted to. There is something wrong with the accuracy" Citation 2: "the screen has an offset, right"	improve accuracy of touchscreen
U24	iPhone gesture was expected	refer to E09
U26		refer to E01
U27		refer to E01
U02	In conjunction with widget	refer to E01 offer a context menu with help function, after selecting function with delay
U07	"He thinks the cause of the different behavior roots in the mental model ... "	change 3D model from "Scene in Hand" to "Eyeball in Hand"
U08		refer to U07
U10		refer to U09
U12		refer to U09
U13	One time zooms in, the other time no reaction after double-tap	remove double-tap function or use it consistently (exact function to be defined in this case)
U20		refer to E01
U28		improve system performance, remove or drastically reduce delays
U31		refer to U19
U33	Category changed (Problems using widget -> Mental Model)	disable elevation going underground refer to U07
U03		don't overlay controls on another (e.g. rotate function on zoom ring) or hide other function (buttons and ring) while one function is active
U05		refer to E09
U06	Seen many times from one case	refer to U01
U16	Due to getting lost	don't reset view when touching an object
U17	Original: unexpected view reset	refer to U16
U29	Citation: "hemisphere control is maybe a more intuitive sensor, because you have both (rotate & pitch) at the same time"	"Hemisphere" control was usually not discovered as well as only used by very few users -> remove function
U32		refer to U01, U03, E01
U35	Problem using elevation gesture correctly	refer to U01, E07
U36	Citation: "pitch icon doesn't describe its function properly	refer to U01

Addendum 9. Usability Evaluation 1 - Interaction Success Rate

[illegible]

Addendum 10. Usability Evaluation 1 - User Expectations

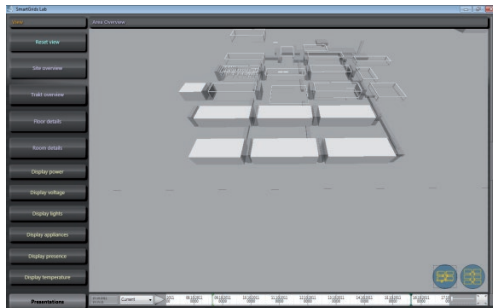
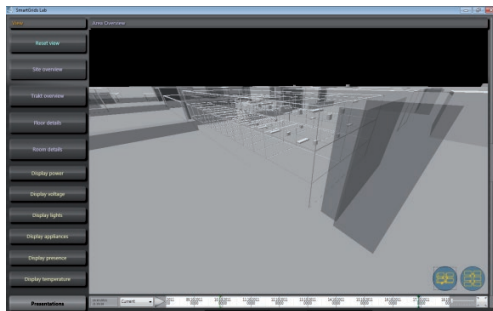
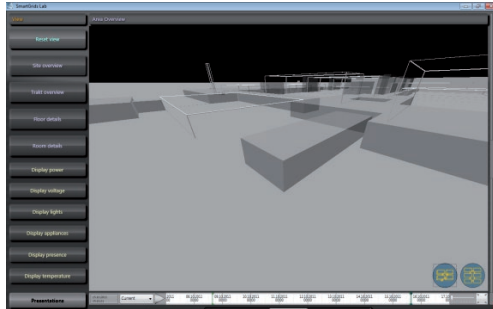
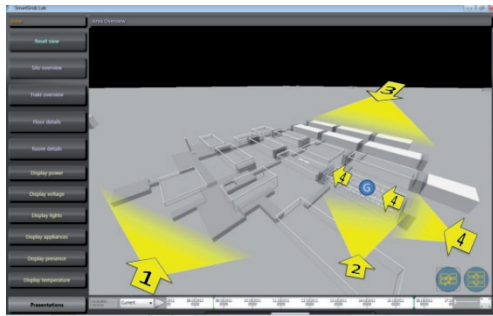
ID	Expectation	Reference	Occurrence	Priority	Report	Usability Category	Affected Component
E17	Faster reaction of system & widget	1, 4, 6, 8	5	1	x	Reaction	System
E18	No delay for the widget to display	1, 3, 6, 8	4	1	x	Reaction	Widget
E29	Descriptions on the buildings themselves	6, 5, 2, 5	4	1	x	Guidance Orientation	Model
E37	Key instructions	6, 8, 2, 9	4	1	x	Guidance Information	Help Functions
E09	It should react / behave like an iPhone	4, 1	2	1		Interaction	Gestures - non Widget Interaction
E10	Use uniform pattern for interacting	8, 4	2	1	x	Interaction	Gestures - non Widget Interaction
E14	Omit the widget and just use gestures	3, 1	2	1	x	Interaction	Gestures - non Widget Interaction
E32	Landmarks to orientate	4, 8	2	1	x	Guidance Orientation	Model
E33	Colors to distinguish different things	2, 9	2	1	x	Guidance Orientation	Model
E01	Widget must be intuitive to use (how to get it and how to keep it)	9	1	1	x	Interaction	Widget
E06	If the widget is under my finger, it should stay there	3	1	1	x	Interaction	Widget
E40	Help-instructions for the functions	5	1	1	x	Guidance Information	Help Functions
E41	Info about the sensors	2	1	1		Guidance Information	Help Functions
E42	Interested to see what I can control in my office	6	1	1		Guidance Information	Help Functions
E03	Widget should stay on, once activated	5, 4	2	2		Interaction	Widget
E02	Widget should be smaller - distracts what is behind	5	1	2		Interaction	Widget
E04	Likes the widget, but didn't understand the function clearly	2	1	2		Interaction	Widget
E05	Widget Icons must be intuitive	5	1	2		Interaction	Widget Control
E07	Enable elevation with one finger	8	1	2		Interaction	Widget Control
E08	Add symbol on half circle	8	1	2		Interaction	Widget Control
E11	Clear & intuitiv functions and symbols	1	1	2		Interaction	Gestures - non Widget Interaction
E12	Interaction must be simpler	9	1	2		Interaction	Gestures - non Widget Interaction
E13	Separate the movements of the dimensions	4	1	2		Interaction	Gestures - non Widget Interaction
E15	Reduce # of navigation possibilities	1	1	2		Interaction	Gestures - non Widget Interaction
E16	The widget should display faster	4	1	2		Reaction	Widget
E19	Reduce reaction time for panning	8	1	2		Reaction	Widget Control
E20	I don't think 3D nav. isn't necessary	2	1	2		questioning 3D	Model
E22	It's a big step if you have no experience in manipulating a 3D model	9	1	2		questioning 3D	Model
E23	The 3D model is usefull to show alarms	4	1	2		questioning 3D	Model
E24	A hierarchical interface might be clearer	4	1	2		questioning 3D	Model
E25	For presenting Smart-Grid, such an interface / model is not needed	4	1	2		questioning 3D	Model
E26	Missing menue buttons (on the left), should show effect on the model	5	1	2		miscellaneous	Model
E28	Buttons on the left confused me	2	1	2		miscellaneous	Navigation
E30	More realistic model	6	1	2		Guidance Orientation	Model
E34	SGD needs to be simpler, less functions	1	1	2		Guidance Orientation	Controls
E35	Textures on the ground & maybe some trees	8	1	2		Guidance Orientation	Model
E21	Wouldn't be 2D more appropriate?	1		2		questioning 3D	Model
E27	A button to jump to a certain building could be helpful	2	1	3		miscellaneous	Navigation
E31	Facade with windows, green between buildings	6	1	3		Guidance Orientation	Model
E36	Model need to look more interesting	1	1	3		Guidance Orientation	Model
E38	Need an invitations	5	1	3		Guidance Information	Model
E39	Background-info	5	1	3		Guidance Information	Help Functions

ID	Remarks	proposed solution
E17	#8 mentioned it 2 times in other words	refer to U28
E18		refer to U28
E29	- it could help to have descriptions on the buildings themselves - pop-up should be used for help and orientation - expects orientation labels in the model	- add description for building nbr. and main entrances - refer to U29 (???)
E37	- Key-Instructions {...} would be helpful - give users a hint what they can do or search - expects help functions of instructions - need some instructions or short manual before I use the system	help function explaining the model as well as its functionality refer to E01
E09		replace widget with common gesture control
E10		refer to E09
E14	(see the photo with Reaction on it)	refer to E09
E32	- landmarks would help orientation - give hints for orientation, such as the fountain	add orientation helps outside the buildings (objects like fountain, trees, geographic directions, streets, forecourt)
E33	- e.g. sensors, objects - some colours could be helpful	add (different) colours for active objects make the active objects more realistic (also in size)
E01		help function explaining the widget. Evtl. pop-up a help window at first time use
E06		refer to U09
E40		refer to E37
E41	widget is meant	refer to E01
E42		refer to E37
E03		delay widget to hide it, when touching finger has been (accidentally) released
E02		refer to E09
E04		refer to E01
E05		refer to E01, U01
E07		enable elevation function with one finger -> consistency with other functions
E08		refer to E01, U01
E11		refer to E01, U01
E12		refer to E09, E15
E13		introduce expert / normal user mode refer to U07
E15		reduce degree of freedom
E16		refer to U28
E19		refer to U28
E20		- OUT OF SCOPE -
E22		refer to E15 refer to U07
E23		- OUT OF SCOPE -
E24		- OUT OF SCOPE -
E25		- OUT OF SCOPE -
E26		remove menues / function buttons which have no (visual) reaction, or enable them context sensitive
E28		refer to E26
E30	more realistic model would have helped to orient oneself better	add realistic colours to the static objects (green grass)
E34		refer to U07
E35		refer to E30, E32
E21		- OUT OF SCOPE -
E27		
E31	seeing facade with windows, having some green between buildings would help to make it more attractive	- make the static objects more realistic - refer to E30
E36	model need to look more interesting and not as dismal	refer to E30, E31
E38	- Need to have an idea about using it. Need an invitation 'come and touch me...'	e.g. add a video showing the model navigation, running as screensaver
E39	wants some background info about the SGD; development and how to use it	refer to E37

Usability Testing 2

Instruction

- Reset the view before starting a task
- Please indicate when you start this task and when you think you are finished



Task 1

Please try to bring the main entrance of the CRC (Corporate Research Center) into the middle of the screen.

Please refer to the illustration on the left.

Task 2

Try to find the wing with most details shown in the inside of it (Wing G). Try to move in such a way that you see the wing magnified across the screen, as indicated on the left.

Task 3

Try to see the middle wing in the very back position right from behind.

Please refer to the illustration on the left.

Task 4

Position yourself at the right hand side of wing (G).

Then move to the second floor of the building and walk through the corridor until the end. Then look back to see where you came from.

Please refer to the illustrations on the left.

Standardized Interview

Ask precisely one question after the other

Additional questions for clarification only are ok

First Test: ☐ Test A / Solution 1 ☐ Test B / Solution 3
Second Test: ☐ Test B / Solution 3 ☐ Test A / Solution 1

Test Person:	Date / Time
--------------	-------------

General impression, feeling (chilling down and opening conversation)
1. How do you feel after this test?

Intuitiveness
2. What solution helped you to get along with the system immediately? (affordance, getting into the topic)
3. How did the use of the widgit meet your expectations (Test A)?
4. How did the gestures meet your expectations (Test B)?

Gestures: The first/second test was with gestures-only. (to make clear what test we talk about)
5. What gestures worked well?
6. What gestures did not work well?
7. How could they be improved?
8. What gestures are you familiar with?

--

Widget yes or no
9. What solution did you prefer? Widget or gestures-only? (general) 9a. Please tell us why.
10. How did the widget support you to navigate through the model (intuitiveness)?
11. How did the gestures support you to navigate through the model (intuitiveness)?
12. Which solution was easier to handle with your fingers? (ergonomics)

3D-Metaphor
13. What model behavior met your expectations better, especially when you look at rotation? (mental model) 13a. Please tell us why.
14. Which model gave you more control? (controllability)

Feedback and wrapping-up
15. Is there anything else you would like to tell us? Thank you very much for your help!

Model Behavior (General / SIH / EIH)

Issues from first evaluation: (E17), U18, U19, U28, U31

General:

- Was the user irritated by certain design, colors or color changes of the model?

Distinguished between SIH / EIH:

- Did errors occur (e.g. system did not react)?
- Was the user irritated by model jumps?
- Was the user irritated by delays and cumbersome reaction of the model?

Widget Behavior

Issues from first evaluation: E01, E03, E05, E06, E07, E10, E16, E17, E18, U01, U03, U04, U09, U20, (U28)

- Did widget jumps occur, and was the user irritated?
- Was the user irritated by delays and cumbersome operation?
- Did the user have problems operating the widget?
- Did the widget operate as the user expected (axes, directions, scaling-factors)?

Gestures Behavior

Issues from first evaluation: E09, E14, U22, U23, U24, U25

- Was the user irritated by delays and cumbersome operation?
- Did interferences occur while operating (e.g. touching with another finger), and was the user irritated?
- Did the user have problems executing the gestures?
- Did the gestures operate as the user expected (axes, directions, scaling-factors)?

Metaphor (SIH / EIH)

Issues from first evaluation: E12, E15, U07, U08, U30, U33, U34

Distinguished between SIH / EIH:

- Was the user irritated by the way he had to move (within) the model?
- Was the user irritated by the viewpoint and/or point of operation (pivot)?

Task Completion

How did the user complete the different tasks?

Comparison between solution A (*Scene-in-Hand* Metaphor with Widget Interaction) and B (*Eyeball-in-Hand* Metaphor with Gestures-only Interaction) in Prose

Model Behavior

Issues from first evaluation: (E17), U18, U19, U28, U31

General:

Was the user irritated by certain design, colors or color changes of the model?
The color of an object changes to white when selected. Especially “big” objects like the ground plate of the VE confused some of the participants. They did not know what it was meant for (TP2, TP5, TP10).

Double tap sets the view to the touched object and zooms the object. If e.g. the model is touched outside the campus, the view is set to a far outreached point as shown in Figure 10-1 (refer also to U13, which is not implemented)

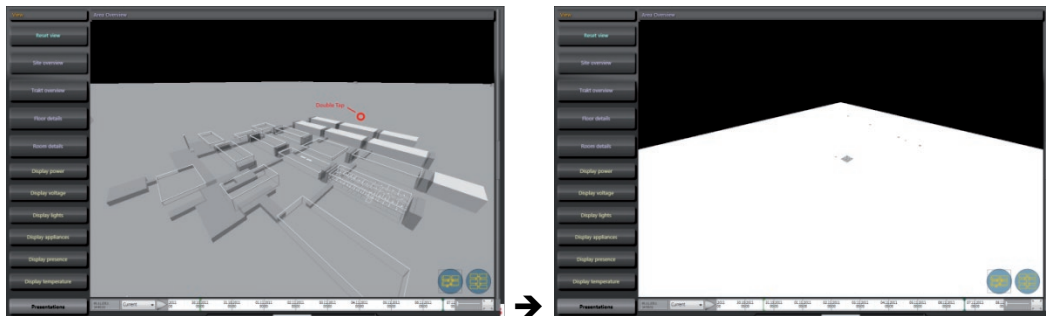


Figure 10-1 Double tap on the ground plate object sets the viewpoint to a far outreached point

SIH:

Did errors occur (e.g. system did not react)?

Tapping on another place within delay time (for function buttons to hide) sets the pan icon to the new touch-point. The correct function would work like moving the function buttons immediately around the new touch-point (refer also to Figure 10-2).

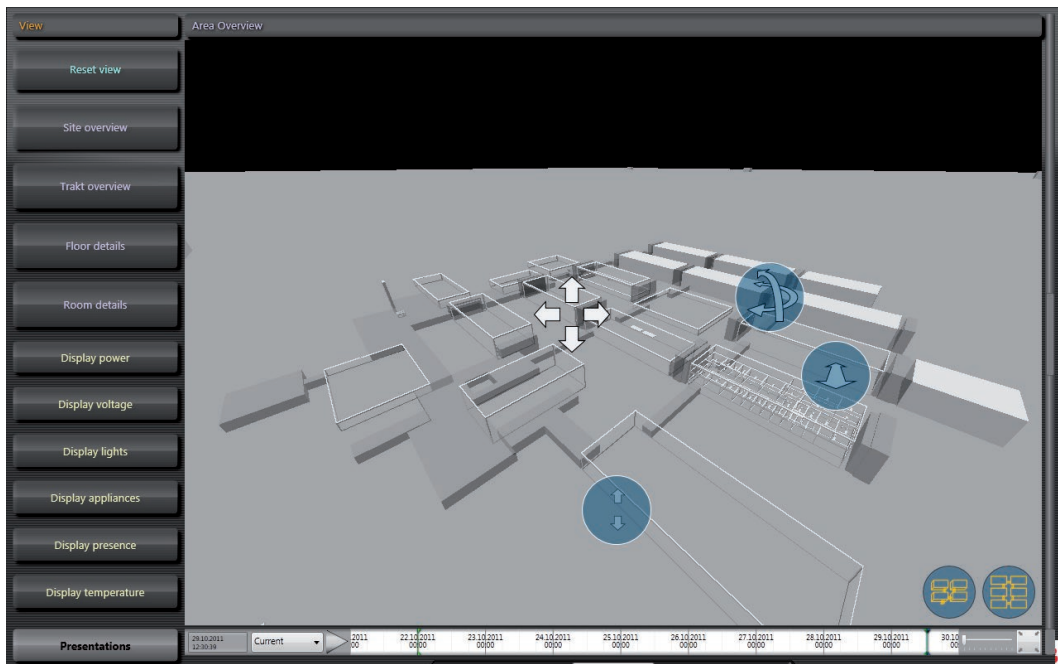


Figure 10-2 Widget error when tapping within hiding time

Was the user irritated by model jumps?

No model jumps occurred.

Was the user irritated by delays and cumbersome reaction of the model?
No irritations of participants could be observed; the system reacted smoothly and was smoothly controllable.

EIH:

Did errors occur (e.g. system did not react)?
No system errors occurred.

Was the user irritated by model jumps?

- Some model jumps occurred (model shifts from some meters up to 100 m away), but participants usually were not concerned or confused about such reaction, they just continued with their task (TP2, TP3, TP4, TP6, TP8, TP10, TP11).

It seems that when doing fast finger movements the sensor interpretation by the system gets stuck (this behavior could not be seen on the X201 tablet, which has a capacitive touch-screen and is more powerful). Some model jumps occurred when releasing the finger after panning (like if it had detected a double tap when releasing, refer e.g. to TP3, 12' 56", TP4, 00' 38" or TP8, 02:06).

It seems that the touch-screen's optical sensors interpret a double tap when a user touches the screen rather smoothly (TP2). Optical sensors are also quite picky for interfering fingers resulting in model jumps.

- 2 zoom jumps occurred without doing a zoom gesture (TP10, 02:35, TP10 12:25 VCAM).

Was the user irritated by delays and cumbersome reaction of the model?
No irritations of participants could be observed, although the system reacted slower than with SIH.

Participants have more been irritated by gesture detection problems rather than by slower (than SIH) model reaction.

Widget Behavior

Issues from first evaluation: E01, E03, E05, E06, E07, E10, E16, E17, E18, U01, U03, U04, U09, U20, (U28)

Did widget jumps occur, and was the user irritated?
No widget jumps occurred.

Was the user irritated by delays and cumbersome operation?
No irritations of participants could be observed; the widget reacted smoothly and was smoothly controllable.

Did the user have problems operating the widget?

- In some cases the widget disappeared too fast for the participants in order to select the functions within time (TP1, TP4, TP5, TP10, TP11).
- Some participants did not realize that they can release the forefinger to use a function and had some difficulties to control the widget with one hand and two fingers (TP2, TP6, TP8).
- Only one participant used both hands to operate the widget (TP7).
- One participant mentioned that he did not understand that panning requires only one finger and all other functions require two fingers (TP7).
- All participants failed in the test, where they had to rotate within a building. *Rotation within a building or near buildings with flat view angle is not useful through rotation center at the center of the model. The user then cannot relate the pivot and gets irritated.*
- Calling-up the widget by touching close to the viewport borders moves some function buttons outside the screen as shown in Figure 10-3. One participant

was confused about this and did not realize to call-up the widget more in the center of the screen instead (TP1).

This behavior may indicate that the participant has not really understood the setting of the pivot.

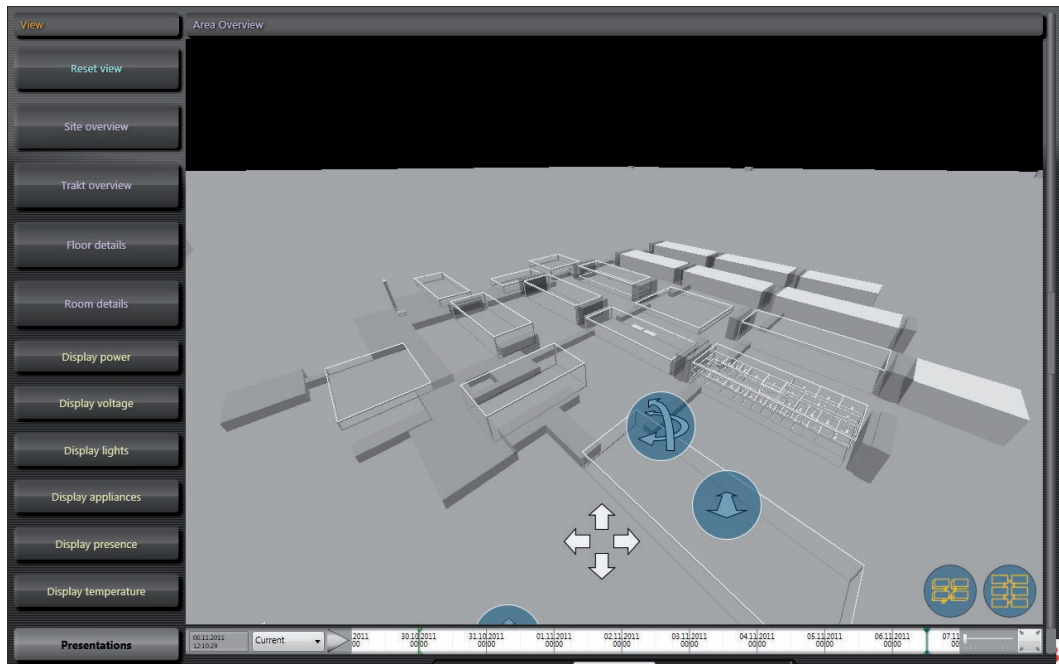


Figure 10-3 Calling-up the widget close to the viewport borders moves some function buttons outside the screen

Did the widget operate as the user expected (axes, directions, scaling-factors)?

- Some participants ignored the widget function buttons at the beginning of the test (TP2, TP4, TP5).
It seemed that the affordance to use the function buttons is not distinct enough.
- The scaling of the pan function when moving within buildings was slightly too big (TP2, TP4).
- Some participants expected function buttons to be activated and then to use this function by moving like with panning (TP8, TP10).

Gestures behavior

Issues from first evaluation: E09, E14, U22, U23, U24, U25

Was the user irritated by delays and cumbersome operation?

- More than half of the participants executed rotation and/or pitch gesture unintentionally, but due to cumbersome system reaction they did not realize and could not repeat this gesture when needed (TP1, TP5, TP6, TP7, TP8, TP11).
We assume that some participants were not able to explore and learn two-finger swipe gestures due to cumbersome reaction, when executing the gesture unintentionally. The participants could not relate the reaction of the system to the executed gesture because of the reaction delay and jolting movements.
- The system struggled sometimes to detect two-finger swipe gestures at all (TP1, TP3, TP5, TP8, TP11). After releasing the fingers for about half of a second, the detection then usually worked.

Did interferences occur while operating (e.g. touching with another finger), and was the user irritated?

No interferences occurred unless those described in the EIH model behavior.

Did the user have problems executing the gestures?

One participant found that the two-finger swipe gestures (movement) have been unnatural (TP4) and struggled operating it correctly.

Did the gestures operate as the user expected (axes, directions, scaling-factors)?

No irritations of participants could be observed neither did participants complain about expecting some other behavior of a gesture. One participant wanted to use double tap on a building to zoom it (TP5).

Metaphor (SIH / EIH)

Issues from first evaluation: E12, E15, U07, U08, U30, U33, U34

SIH Metaphor:

Was the user irritated by the way he had to move (within) the model?

- Some participants did not understand pan function, as soon as they had to move through a building (corridor). They did not understand that they move the model on the same height by panning (TP1, TP5, TP8).
- Some participants did not realize to use pan in order to move through a building and used zoom instead (TP4 and TP10 at the beginning, TP5, TP6). *This behavior may indicate that the participants have not understood the principle of the model respectively the difference between panning and zooming.*
- Participants did not use the elevation function and did not realize the difference between elevation and pitch when navigating through buildings.
→ *Possibly move the elevation function from the widget to a separate side bar.*

Was the user irritated by the viewpoint and/or point of operation (pivot)?

No irritations of participants could be observed unless the problem with rotating within a building described in the section widget behavior. Only one participant mentioned that he does not know where the pivot was set for rotation (TP7).

It seems that participants usually did not realize and had not been confused, where the pivot for rotation and zooming was set.

EIH Metaphor

Was the user irritated by the way he had to move (within) the model?

- Some participants did not realize that they had to zoom to move through a building and tried to use pan gesture instead (TP1, TP6, TP8). *This behavior may indicate that the user has not understood the EIH metaphor respectively the difference between panning and zooming.*
- Some participants were irritated by the wide angle perspective, such that they got the impression that panning does somehow rotate the model (TP1, TP6, TP7, TP10).
- No participant was confused by panning on z-axis (heave), they just used to zoom-out to get more height when e.g. being too close to the building. (TP2, TP5, TP6, TP7, TP8, TP10, TP11).
- Most of the participants did not use the pitch gesture to get 90° horizontal view to be able to “walk” horizontally” on the same height by zooming (TP1, TP2, TP4, TP5, TP6, TP7, TP8, TP10, only TP3 and TP11 realized to set pitch to 90° and zoom).

Was the user irritated by the viewpoint and/or point of operation (pivot)?

No irritations of participants could be observed. One participant expected the zoom pivot in the middle of the two fingers (TP7).

Task Completion

Solution A: *Scene-in-Hand* Metaphor with Widget Interaction:

How did the user complete the different tasks?

All participants were able to complete all the tasks within a mean time of about 9 minutes (refer to addendum *Usability Evaluation 2 - Intuitiveness Matrix*). No instructions had been given at all. Exceptions were made in task 4 (refer to addendum *Usability Evaluation 2 - Test Scenario*), where no participant could rotate within a building as described in the section widget behavior as well as for one participant who was not able to find out other functions than panning (TP1) without getting any hint.

Solution B: *Eyeball-in-Hand* Metaphor with Gestures-only Interaction

How did the user complete the different tasks?

All participants were able to complete all the tasks within a mean time of about 11 minutes (refer to addendum *Usability Evaluation 2 - Intuitiveness Matrix*). All participants required some hints to find out the two-finger swipe gestures. One participant was not able to find out other gestures than panning (TP1) without getting any hint.

Legend

Comments: comments, assumptions etc. are written in *italic*

TP Test Participant

Addendum 15. Usability Evaluation 2 - Intuitiveness Matrix

	pan x/y/z		zoom		rotate		rotate alt1		rotate alt2		pitch		elevation		Task Duration [min]	
Test Participant	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1 AB	1	1	5	5	4	5	/	3	/	3	4	5	4	/	12	12
2 BA	1	1	5	1	3	4	/	1	/	1	3	4	3	/	8	8
3 AB	1	1	1	1	1	5	/	1	/	1	1	5	4	/	5	8
4 BA	1	1	3	1	3	5	/	1	/	3	3	5	3	/	8	10
5 AB	1	1	3	3	3	5	/	1	/	3	3	5	3	/	12	10
6 BA	1	1	1	1	1	5	/	1	/	1	1	5	3	/	6	12
7 AB	1	1	1	1	1	5	/	5	/	1	1	5	1	/	9	9
8 BA	1	1	3	1	3	5	/	5	/	1	3	5	3	/	11	10
10 BA	1	1	5	1	4	5	/	5	/	5	4	4	4	/	10	16
11 AB	1	1	1	1	1	5	/	1	/	1	1	5	3	/	7	10
Total	1	1	2.8	1.6	2.4	4.9		2.4		2	2.4	4.8	3.1		8.8	10.5

rotate alt1 1-finger arc gesture

rotate alt2 circular 2-finger twist gesture

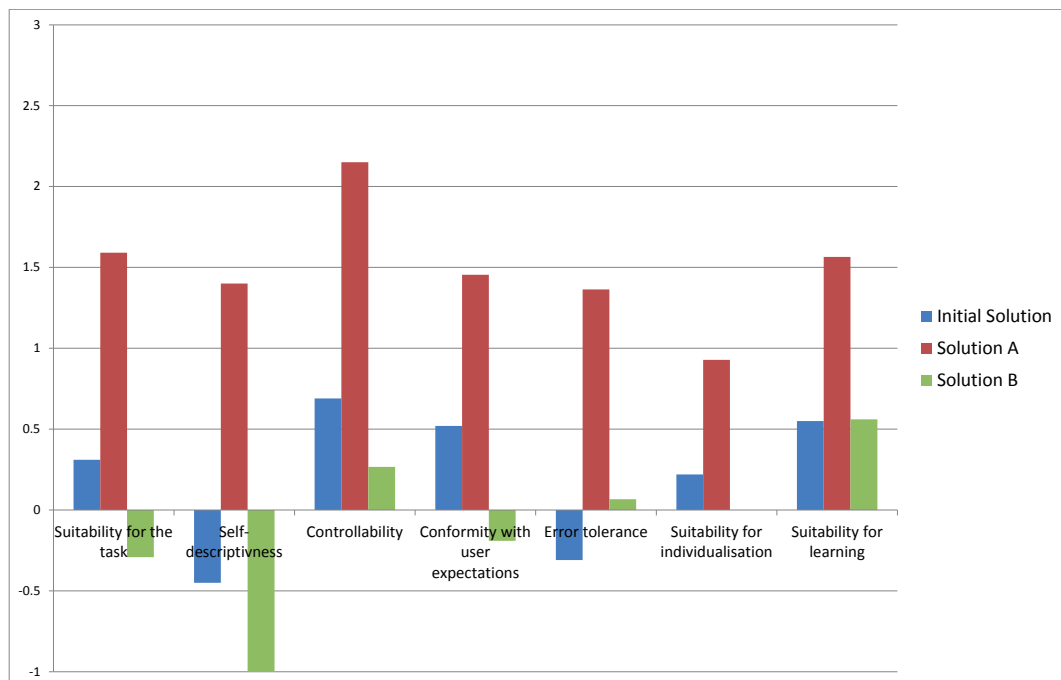
Intuitivity-Scale	
1	very easy
3	difficult
5	unable

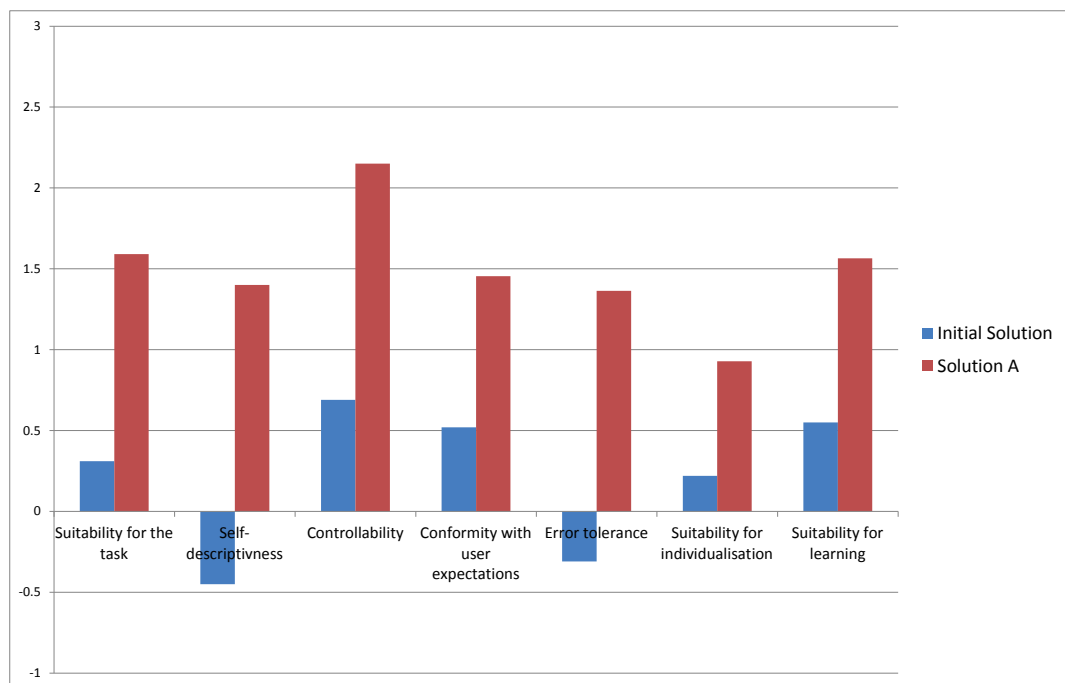
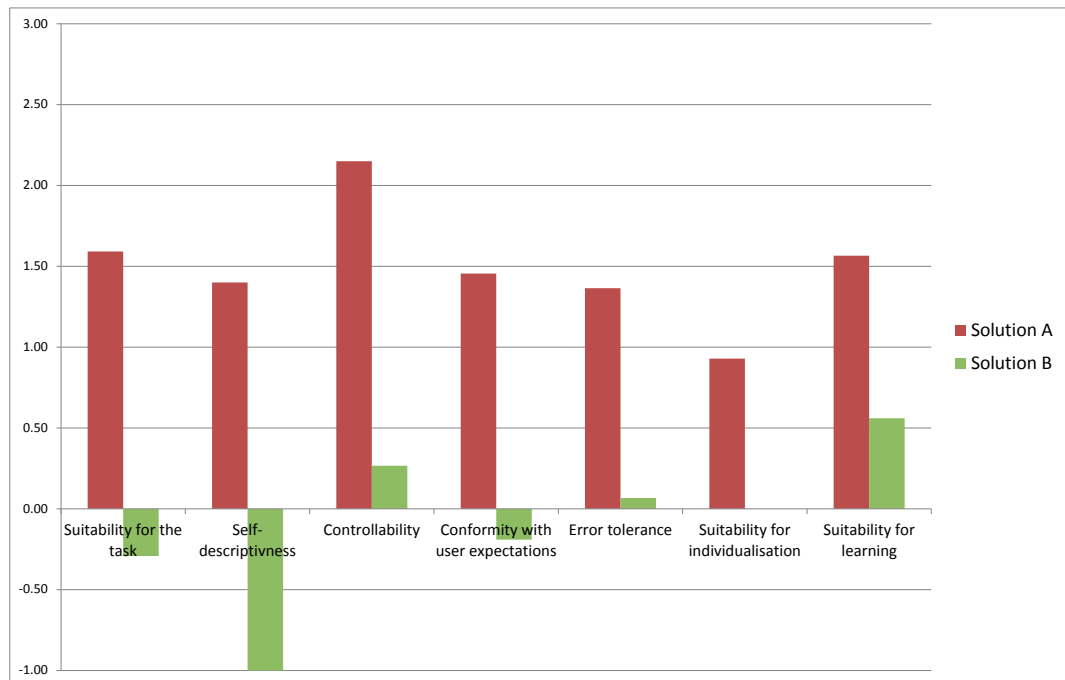
Addendum 16. Rating of Initial Solution, Solution A and B According to ISO Questionnaire

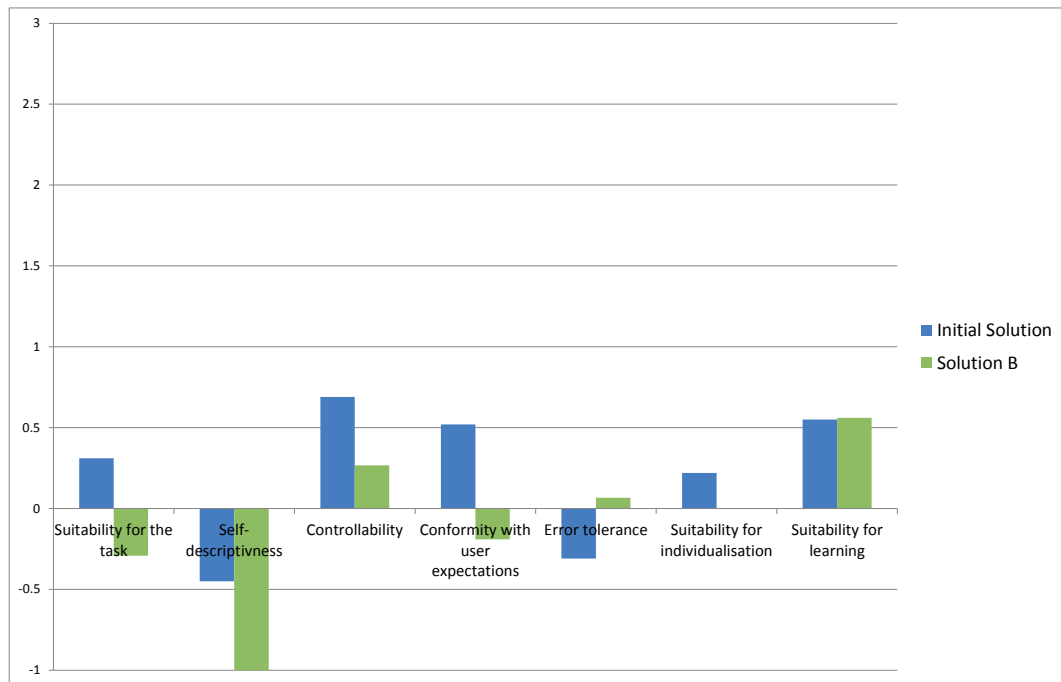
			Solution A					Solution B				
			Testperson									
Design principle	Question	Aspect of question	2	4	6	8	10	1	3	5	7	11
Suitability for the task	st1		-1	-2	2	1	2	-2	-2	0	1	2
	st2		2	1	2	2	3	-1	1	1	2	2
	st3		1	1	3	3		-1	-1	2	-2	-3
	st4		1		3	1	1	-1	-2	-2	2	0
	st5		2	2	3	2		-1	0	-2		0
Self-descriptivness	sd1		1	1	3	2	2	-2	-2	-3	-2	1
	sd2		1	2	3	2	2	0	0			1
	sd3		2	0	3	-1	1	-1	-3	0	-1	1
	sd4		0	0				-1	-1		-1	
	sd5		2	0		2		-1	-2		-2	
Controllability	ct1	requires superfluous (überflüssig) input	3	3	3	3		0			-2	1
	ct2		-1	3	3	2	2	0		0	2	2
	ct3		2		3			0				1
	ct4		-1		3	3	1	-2		2	0	
	ct5		2	3	3	1	2	-2		0		2
Conformity with user expectations	ce1		-2	2	3	3	1	-2	1	2	1	3
	ce2		2	2	3	-1		-1	-1	0	2	
	ce3		2	2	3	1	2	-3	-1	-3	1	
	ce4		-1	2	2	0	-1	-2	-2	-2	2	
	ce5		2	2	3			-1	0	0	2	
Error tolerance	et1		1	3	2	3	1	0	-1	2	2	
	et2			-3	3	-1		0	-2			
	et3	display error messages (na!)						0	0			
	et4		2	3		1		0	-1	2	1	
	et5							0	0		-2	
Suitability for individualisation	si1		-2	2	2	2		-2	1	-1		1
	si2		-1			2		-1	1		-2	1
	si3		-1	2	3	2		-3	0	0	1	2
	si4		-1			2		-2	-1	1		2
	si5		0			1		-2	-1	1	2	2
Suitability for learning	sl1		-1	2	3	2		0	2	2	1	3
	sl2		1	2	2	3	1	0	-1	2	2	2
	sl3		0	2	3	2	2	0	-2	1	2	-1
	sl4		0	2	3	1	2	0	0	3	2	0
	sl5		-2	2	3	1		-1	-3	-2	1	1
Personal Profile	pr1	know SGD	-3	-3	-2	-3	-3	-3		-3	-3	-3
	pr2	using SGD how long (d / h)	1		0.8	0.5	0.5	0.5	0.5		1	
	pr3	have been using computer for how long (y)	20	18	18	20	20	20	20		20	22
	pr4	have been using internet for how long (y)	10	12	10	15	10	10	10		20	15
	pr5	using SGD how often (sessions per month)										
	pr6	using computer how often / week (h)	50	45	60	50	50	40	40		40	60
	pr7	using internet how often / week (h)	20	20	20	2	10	5	15		5	20
	pr8	gender	m	f	m	m	f	m	m	m	m	m
	pr9	age (years)	27	40	30	35	43	63	37	37	47	43
Opinion	bf	best function										
	wf	worst function										

Design principle	Question	Solution A					
		Question based		Design Principle based		Overall	
		Average	SD	Average	SD	Average	SD
Suitability for the task	st1	0.40	1.82	1.59	1.26	1.53	1.40
	st2	2.00	0.71				
	st3	2.00	1.15				
	st4	1.50	1.00				
	st5	2.25	0.50				
Self-descriptivness	sd1	1.80	0.84	1.40	1.14		
	sd2	2.00	0.71				
	sd3	1.00	1.58				
	sd4	0.00	0.00				
	sd5	1.33	1.15				
Controllability	ct1	3.00	0.00	2.15	1.27		
	ct2	1.80	1.64				
	ct3	2.50	0.71				
	ct4	1.50	1.91				
	ct5	2.20	0.84				
Conformity with user expectations	ce1	1.40	2.07	1.45	1.50		
	ce2	1.50	1.73				
	ce3	2.00	0.71				
	ce4	0.40	1.52				
	ce5	2.33	0.58				
Error tolerance	et1	2.00	1.00	1.36	1.91		
	et2	-0.33	3.06				
	et3						
	et4	2.00	1.00				
	et5						
Suitability for individualisation	si1	1.00	2.00	0.93	1.59		
	si2	0.50	2.12				
	si3	1.50	1.73				
	si4	0.50	2.12				
	si5	0.50	0.71				
Suitability for learning	sl1	1.50	1.73	1.57	1.31		
	sl2	1.80	0.84				
	sl3	1.80	1.10				
	sl4	1.60	1.14				
	sl5	1.00	2.16				
Personal Profile	pr1						
	pr2						
	pr3						
	pr4						
	pr5						
	pr6						
	pr7						
	pr8						
	pr9						
Opinion	bf						
	wf						

		Solution B				Overall	
		Question based		Design Principle based			
Design principle	Question	Average	SD	Average	SD	Average	SD
Suitability for the task	st1	-0.20	1.79	-0.29	1.60	-0.08	1.58
	st2	1.00	1.22				
	st3	-1.00	1.87				
	st4	-0.60	1.67				
	st5	-0.75	0.96				
Self-descriptivness	sd1	-1.60	1.52	-1.00	1.25		
	sd2	0.33	0.58				
	sd3	-0.80	1.48				
	sd4	-1.00	0.00				
	sd5	-1.67	0.58				
Controllability	ct1	-0.33	1.53	0.27	1.44		
	ct2	1.00	1.15				
	ct3	0.50	0.71				
	ct4	0.00	2.00				
	ct5	0.00	2.00				
Conformity with user expectations	ce1	1.00	1.87	-0.19	1.81		
	ce2	0.00	1.41				
	ce3	-1.50	1.91				
	ce4	-1.00	2.00				
	ce5	0.25	1.26				
Error tolerance	et1	0.75	1.50	0.07	1.28		
	et2	-1.00	1.41				
	et3	0.00	0.00				
	et4	0.50	1.29				
	et5	-0.67	1.15				
Suitability for individualisation	si1	-0.25	1.50	0.00	1.57		
	si2	-0.25	1.50				
	si3	0.00	1.87				
	si4	0.00	1.83				
	si5	0.40	1.82				
Suitability for learning	sl1	1.60	1.14	0.56	1.61		
	sl2	1.00	1.41				
	sl3	0.00	1.58				
	sl4	1.00	1.41				
	sl5	-0.80	1.79				
Personal Profile	pr1						
	pr2						
	pr3						
	pr4						
	pr5						
	pr6						
	pr7						
	pr8						
	pr9						
Opinion	bf						
	wf						







Addendum 17. Configurable Properties

The table below describes the most relevant switches to configure the behavior of the 3D user interface for both metaphors, *eyeball-in-hand* (EIH) and *scene-in-hand* (SIH).

UI Switch	Property value	Property set by switch	Property default	Effect	SIH	EIH	Widget	Gesture
/hifi	HiFi3D	TRUE	TRUE	Sets high fidelity 3D rendering 1)	X	X	X	X
/lofi	HiFi3D	FALSE	TRUE	Sets lower fidelity 3D rendering 2)	X	X	X	X
/synthetic	SyntheticData	TRUE	FALSE	Uses simulated data 3)	X	X	X	X
/fullscreen	FullScreen	TRUE	FALSE	Sets window to fullscreen after startup	X	X	X	X
/eyeballinhand	UI-WorldInHand	FALSE	TRUE	Switchs model to eyeball-in-hand mode		X	O	X
/eyeballinhandmove	UI-WorldInHandMove	FALSE	TRUE	Sets heave and sway gesture moves to EIH 4)	O	X	O	X
/moveabsolute	UI-MoveAbsolute	TRUE	FALSE	Sets scaling for move to absolute 5)	X	O	X	O
/scalespeedbyheight	UI-ScaleSpeedByHeight	TRUE	FALSE	Reduces scaling factor below 10 meters height 6)	O	X	O	X
/rotateatcenter	UI-RotateAtCenter	TRUE	FALSE	Sets the rotation center to viewport center 7)	X	(X)	X	(X)
/zoomatcenter	UI-ZoomAtCenter	TRUE	FALSE	Sets the zoom center to viewport center 8)	X	(X)	X	(X)
/simplewidget	UI-SimpleWidget	TRUE	FALSE	Use of the new (simplified) widget			X	
/legacymode	UI-LegacyMode	TRUE	FALSE	Set widget back to original delays 9)			X	
/smoothmotion	SmoothMotion	TRUE	FALSE	Sets rubber band effects	X	X	X	X
/nopopup	InfoPopup	FALSE	TRUE	Disable object info flags	X	X	X	X
/viewspacemove	UI-ViewSpaceMove	TRUE	FALSE	Transforms the z*-axis to the z-axis for elevation	O	X	X	
/xzpanactive	UI-XZPanActive	TRUE	FALSE	Transforms the pan function to z-axis	O	X	X	
/gesturemode	UI-GestureMode	TRUE	FALSE	Activates gestures	O	X		X
Legend:								
	Scene-in-hand metaphor							
	Eyeball-in-hand metaphor							
X	Only possible for this metaphor/interaction							
O	Possible for this metaphor/interaction, but not preferred							
(X)	Activated by metaphor/interaction type (implicite)							
X	Setting for Usability Evaluation 2, SIH tests *							
X	Setting for Usability Evaluation 2 EIH tests **							
X	(additional) Setting for Usability Evaluation 2 EIH Hallway-tests with panning in gesture-direction ***							