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HUMAN INTERFACE DEVICES AND BUILDING INFORMATION SYSTEMS – A USABILITY STUDY

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ABSTRACT

Building Information Systems handle non-abstract data that is directly related to the built environment (e.g., indoor climate, energy use, building systems' states). Building information terminals offer a way to present building data to target groups with differing educational backgrounds. Such terminals are used frequently. Therefore, they should provide a good learning experience. The present contribution compares three input devices to identify the one that facilitates the best learning experience in a building information terminal use case. The proposed application is a web frontend of an open source building information system that is developed at the Department of Building Physics and Building Ecology, Vienna University of Technology (VUT), Austria. A usability study with 30 participants is conducted. The participants use three input devices – keyboard and mouse, a touch screen and a gesture input device. Gesture input allows a user to access a system without being in direct physical contact with the input device. An RGB optical sensor (red, green, blue) and an infrared sensor capture the users' body movements. The detected gestures are translated into commands. The purpose of the study is to identify an optimal setup for a building information system terminal at VUT.

KEYWORDS

Building Information System, Usability, Gesture Input, User Interface Design

1. INTRODUCTION

The building sector is responsible for up to 40% of the overall energy usage in many countries (Graubner and Hüske 2003). Mahdavi et al. 2008 state that the optimization of building performance depends on information about energy and environmental performance. Building information systems collect, process and communicate this information. The Department of Building Physics and Building Ecology, VUT, Austria developed a building information system that provides access to building data streams via a number of client applications. The Monitoring System Toolkit (MOST – MOST 2012) is a vendor and technology independent building monitoring framework (Zach et al. 2012). Building data streams are collected, processed and distributed via standardized service procedures. To access the data aside from the service structure, a Matlab framework and a web application were developed. The web application consists of five modules that cover different use cases. Possible user groups were identified during a use case study (Chien et al. 2011). The modules are: desktop, chart, feedback, export and a 3-dimensional (3D) building viewer. The desktop module provides a simplified desktop functionality, similar to an operating system desktop. The chart module generates trend charts based on user-defined time frames. To integrate the building population into the monitoring process, a feedback module collects user specific information via a simple questionnaire. Users communicate to the system their view on the current state (regarding temperature, humidity, etc.) and can therefore actively add “measurements”. The export module provides an interface to export building data to various formats. The 3D building viewer offers an interactive way to access the monitoring structure (Figure 1). Based on the open source tool BimSurfer (BimSurfer 2013), an extension was implemented that allows a user to actively interact with a 3D building model. This interaction process includes the possibility to change the transparency of objects, to expose and to highlight building storeys. A priority of the implementation phase was to display sensor locations and building related data in a 3D space and to offer access to building data to non-professional users. The primary interaction method is drag and drop.

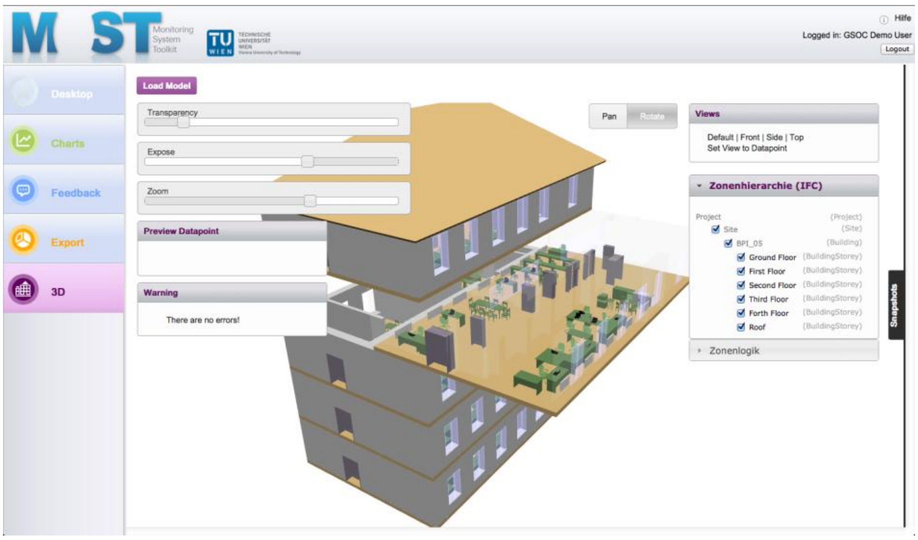

Figure 1. MOST web application

Latest research efforts focused on the optimization of the communication process of building performance data. The developed concepts should be implemented as part of a building information terminal. As the user group definition was widespread the terminal should provide a good learning experience. This premise is software related but also concerns the input and output hardware. Cognitive research was included in the software design process. This contribution deals with the question if human spatial cognitive concepts influence a human-machine interaction process. Therefore, a usability study is conducted that compares the learning effect of three input methods (mouse and keyboard, touch input and gesture input). To allow a comparison of input devices the input operations (click, drag, zoom, pan, rotate) were standardized (Glawischnig et al. 2012). The testing environment uses a 55-inch touch screen, a conventional notebook with a mouse and a keyboard and the Microsoft Kinect gesture input device (Kramer 2012). This relatively low-cost device recognizes the human body form from a 40cm distance onwards. Two sensors (RGB and infrared) monitor the body movement and translate it into computer-understandable commands.

1.1 Navigation Concepts

Everyday life is strongly connected to space. The individual perception of the world is built upon abstractions of our surroundings. The places we visit and the knowledge that we perceive influence the interaction with our physical and virtual environments (Kuhn and Frank 1991). For example, Maglio and Matlock 1998 describe how spatial vocabulary is used on the Internet:

- to *visit* a website
- *follow* a link to a new location
- *move* a file to a folder

The human mind classifies the virtual environment into spaces, which are derivatives of real world phenomena (e.g. haptic spaces, that are derived from touching and other bodily interactions - Mark 1992). The human impressions of the environment are perceived through the senses. Seeing, hearing and feeling the environment forms individual cognitive concepts and categories. These patterns are commonly referred to as image schemata (Johnson 1987). Image schemata can be seen as a generic, abstract term that helps people to establish a connection between different but similar structured states and operations in a system (Raubal et al. 1997). Cognitive research offers insight into cognitive processes that can influence the design of (spatial) information systems. The evaluated MOST web application included spatial cognition concepts in the design process. All user interface elements and logical operations were designed and revised to stay close to real world concepts. Allocating the discussed concepts of human spatial cognition to a building monitoring system implementation raised one question:

Do input methods that directly interact with virtual spaces improve the learning experience?

In this context the word “directly” refers to the following characteristics (Glawischnig 2013):

- **Physical contact**
  Keyboard/ Mouse: Specific devices are needed to interact with the application.
  Touchscreen: The user is in direct physical contact with the output device and the application.
  Gesture Input: No physical contact is established. The body movement is recorded and translated into commands.
- **Hardware specifics**
  Keyboard/ Mouse: The mouse specific speed and accuracy influences the user performance.
  Touchscreen: The touch screen sensitivity holds possible usability issues.
  Gesture input: Resolution and vision field of the sensor, necessary illumination and simulated mouse parameters are critical.

Considering these conditions suggests that a touch input device supports the learning experience more than keyboard and mouse or a gesture input device. Users are in direct physical contact with the output device. The performed actions refer to well known concepts. For example, the action definition of “taking and moving” an item are least abstract for a touch interaction compared to mouse and gesture input. Using the mouse requires a CLICK operation as well as an arm movement in a space (physical table) that is not connected to the virtual space of the application. Before the incoming information is processed, the brain must make a connection between two spaces.

2. USABILITY STUDY

2.1 Design

To compare the learning performance of the three input methods mouse and keyboard, touch input and gesture input, the study evaluates the influence of an input method on the learning performance of an application. The study follows an experimental approach. The participants solve computerized exercises and are directly observed. A 6x1-factorial, bivariate randomized test procedure evaluates the learning process. The six independent variables are the possible input method sequences (Table 1). Every exercise is repeated with every input method. For example, one participant does three exercises on a touch screen. The exercises then are repeated with keyboard and mouse and gesture input (three iterations). The exercise content and testing environment never changes (6x1 factorial). Two dependent variables measure the learning performance:

- TIME
- ERRORS

TIME is the observed time a participant needs to finish the exercise. ERRORS are the usage errors that happen in each exercise cycle (completion of all three exercises). This can be wrong gestures or wrong workflows. The first exercise cycle defines the experimental condition. The two repeating cycles define the control conditions. A comparison of the dependent variables for all input devices provides the basis for the evaluation of the input devices in view of learning efficiency.

Table 1. All possible input device sequences

Run 1	Run 2	Run 3
Keyboard/Mouse	Touchscreen	Gesture Input
Keyboard/Mouse	Gesture Input	Touchscreen
Touchscreen	Keyboard/Mouse	Gesture Input
Touchscreen	Gesture Input	Keyboard/Mouse
Gesture Input	Touchscreen	Keyboard/Mouse
Gesture Input	Keyboard/Mouse	Touchscreen

2.2 Sample

The study consists of 15 male and 15 female participants. The sample size is 30 (n=30). Certain subjective attributes were documented about each participant. Table 2 shows an overview of these attributes for a generic participant. Participants were mostly students at our Building Science and Technology program. Participants' characteristics are determined by three parallelizing conditions:

- No experiences with gesture input devices.
- Possession of a smartphone (mobile phone with touch screen).
- Not familiar with the application.

These conditions indicate that each participant should be familiar with a touch screen and a computer. Optimally the opposite should be the case, but it is hardly possible to find participants who are not familiar with the use of a computer. To catch these limitations, each person is allowed to get familiar with the gesture input device before participating in the study. Furthermore, the familiarity with the input device can be neglected to some extent. In the scope of this study it is assumed that logic errors do not directly correlate with the used input method.

The age distribution of the participants is as follows: 16 between 18 and 25 years old, 12 between 26 and 35 years old and 2 more than 36 years old. This collection of attributes mainly serves planning and documentation purposes. Besides defining parallelizing conditions it offers a basis for including other demographic groups into the experiment.

Table 2. Generic sample person

Name	R.C.
Profession	Master Student – Architecture
Capacity	Needs sensor data for project work. Using information screen when going the administration office. Not familiar with gesture input devices.
Age	25
Socio-demographic characteristics	Not married; in a relationship
Other characteristics and skills	Languages: English, German Is used to work with computers. Owns a smartphone.
Use cases	Historical data access. Application: easy to use.

2.3 Material

The experiment consists of three exercises that are repeated three times with various input methods. Each exercise focuses on one core question. Test case A deals with the perception of the application logic. Test case B concentrates on the perception and manipulation of virtual representations of parts of the real world (large-scale spaces). Test case C combines application logic and visual representations of large-scale spaces.

2.3.1 Test Case A

The first test case introduces the participant to the application:

- Open a building model.
- Search for a specific sensor via sensor name.
- Get familiar with drag and drop.
- Create a trend chart for a sensor.
- Get familiar with the chart representation and extract information.
- Use the zoom functionality.

2.3.2 Test Case B

The second test case uses the 3D module to interact with the building model. The exercise is to recreate the view shown in Figure 2. This exercise includes the following processes:

- Load a building model.
- Use the model object hierarchy.
- Use the 3D viewer functionality.
- Get familiar with the navigation functionality.
- Recall visual information.

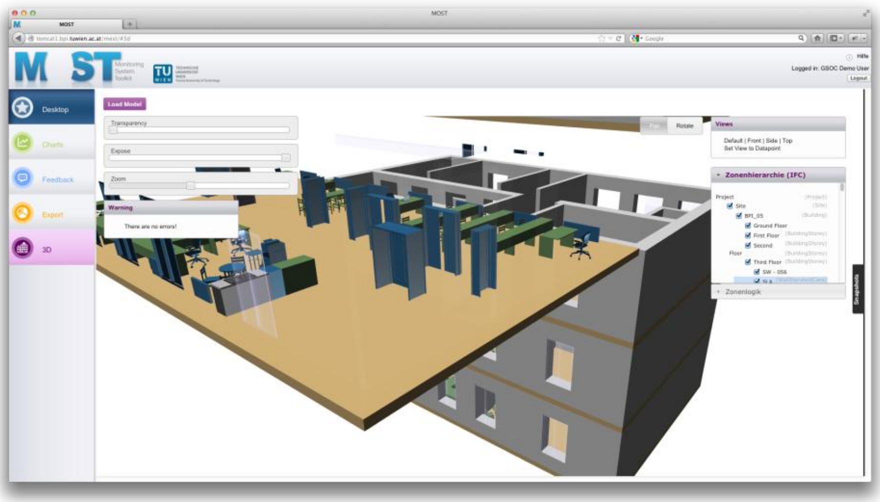

Figure 2. Test case B 3-dimensional exercise view

2.3.3 Test Case C

The third test case combines the principles of exercise one and two:

- Open a module.
- Search for a sensor.
- Drag a sensor from the chart module to the 3D module.
- Interact with the building model.
- Drag a sensor to the chart module.
- Create a chart.

2.4 Procedure

The experiment took place at the Department for Building Physics and Building Ecology, VUT. The participants go through the exercises one at a time and are observed by the experimenter. Figure 3 shows an outline of the experiment room and the positions of the participants and observer. No cycle is conducted with more than one participant at a time.

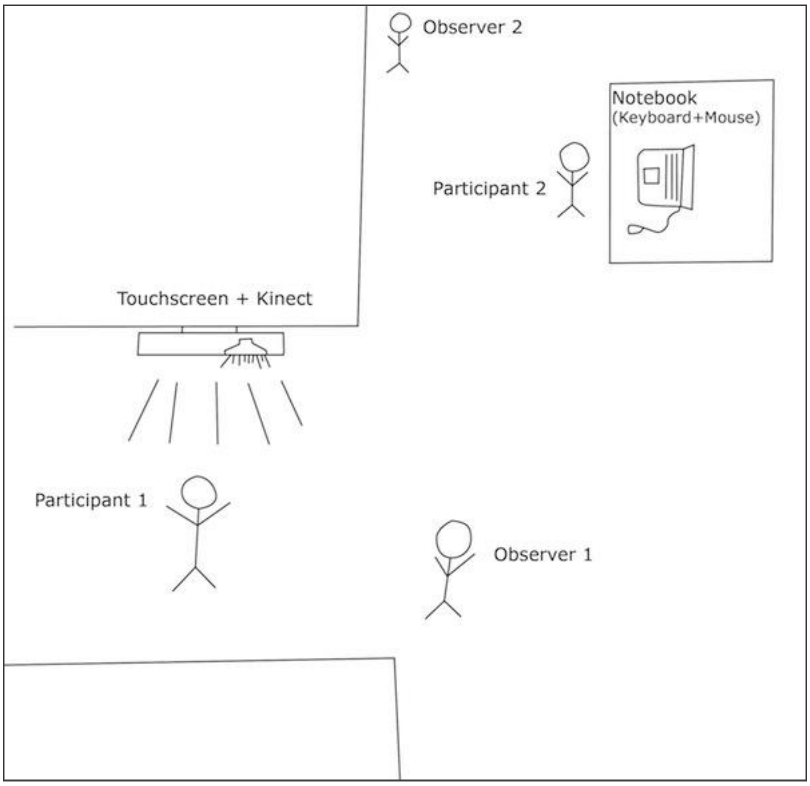

Figure 3. Usability study - experiment setup sketch

The observer welcomes the participant and explains the procedure. This includes:

- General introduction to the Department's research.
- General description of the experiment.
- Introduction to the application concepts (non visual).
- Information on the exact procedure.
- Handing over of the questionnaires.
- Introduction to the input device of the first cycle.

Each input device is introduced right before the participant performs the exercises. The experimenter gives the participant the exercise papers. The participant reads the task assignments and starts once ready. The experimenter records the time and errors. The gesture input training duration takes 15 minutes. The student starts with drawing lines in a simple paint program (Microsoft Paint). Then he/she navigates the web page and plays a simple flash game. The building information application runs on an Apache Tomcat web server. Participants access the web application via two workstations. The first computer is an Apple notebook, the second one a Mini-PC. Both have similar specifications:

- Quad-core processor
- 4 gigabytes RAM
- Integrated graphics card

Workstation 1 is connected to the Information Screen (55 inch) and the Kinect. Workstation 2 is connected to mouse and keyboard and a 24 inch screen. The operating system is Linux Mint and the accessing browser Firefox. The following devices are tested.

- Keyboard and mouse
- Touch screen
- Microsoft Kinect

Electrical light is switched on during the experiments to guarantee consistent conditions for the Kinect. The experiment is concluded by a questionnaire that asks about the personal background and opinion about the application, exercises, and input devices.

3. RESULTS

3.1 Data Aggregation

The analysis and results are descriptive. No explorative or inductive statistical tests are conducted. Given the structure of the sample the statistical significance is not tested, as the results cannot be transferred to other demographic groups. Kinect measurements are excluded from the data analysis. A number of participants could not handle the device operation challenges. Even some participants who found the exercise as such easy or moderately challenging, could not finish the Kinect exercises because of:

- Physical exhaustion: The arms got too tired to finish the exercise.
- Coordination problems: Did not understand how to use the application with a gesture input device.

The time limit to finish an exercise with the Kinect was set to 20 minutes. Given the low number of participants who completed the exercise (less than fifteen), the generated data could not be used: The respective measurements were widely scattered and showed too many extreme outliers to deliver interpretable results. Figure 4 shows the measured durations for exercise 1. Measurements pertaining to exercises, which were not concluded, are not included in the figure.

The five outliers (20 minutes) did not finish the exercise before the end of the time limit. However, the available results indicate that gesture input might be an alternative to mouse, keyboard and touch input in future applications.

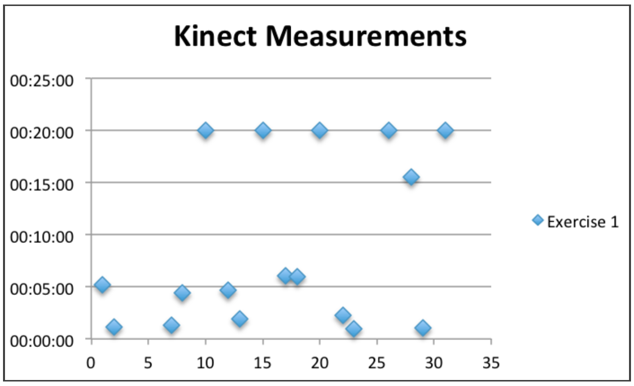

Figure 4. Excluded gesture input measurements.

3.2 Learning Speed

To verify a potential learning progress all the measured exercise durations were compared.

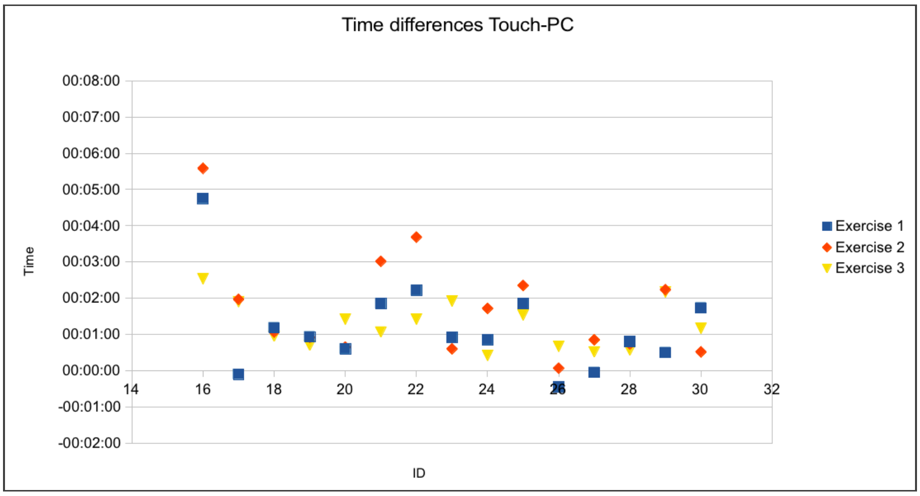

Figure 5. Time differences for all exercises with the experiment sequence *Touch-PC*.

The analysis started with the calculation of differences of the time needed to complete an assignment using touchscreen versus using mouse and keyboard (*Touch-PC*; $Time_{Touch} - Time_{Mouse/\ Keyboard}$). Figure 5 shows the results for the case where the participants completed the exercises faster in the second iteration. Figure 6 shows the corresponding results for the case where participants initially learned the application with mouse and keyboard and repeated the exercises with touch input (*PC-Touch*). The *Touch-PC* group shows higher time differences.

This can be interpreted in two ways: Either touch input requires a higher learning effort than mouse and keyboard or the learning experience with the touch screen is better and therefore the repeating run with mouse and keyboard is more effective. To decide which option applies the learning speed is considered. The learning speed for touch input is calculated by the formula $L = median(T_{T1}) - median(T_{T2})$. The average durations of the *Touch-PC* group $median(T_{T1})$ minus the average touch input durations of the *PC-Touch* group (touch input is the input method of the second exercise cycle iteration) indicate that touch input supports the learning process better than keyboard and mouse. *PC-Touch* measurements are calculated accordingly. The purpose of these calculations is to check the interpretation of the actual measurements.

Table 3. Learning effect indicators.

Learning Effect	Exercise 1 [min:sec]	Exercise 2 [min:sec]	Exercise 3 [min:sec]
Touch Input	00:42	00:32	00:59
Mouse and Keyboard	01:09	01:04	00:39

A participant needs a certain time to learn an application. These durations get shorter when the participant repeats the same exercises for a second time (second iteration). The subtraction of the second iteration durations from the first iteration durations assesses the initial learning performance of the input method that was used for the first iteration. A high result describes a larger influence of the initial learning method. Combining the results from Table 3, Figure 5 and Figure 6 shows that learning an application via touch input provided a better learning experience.

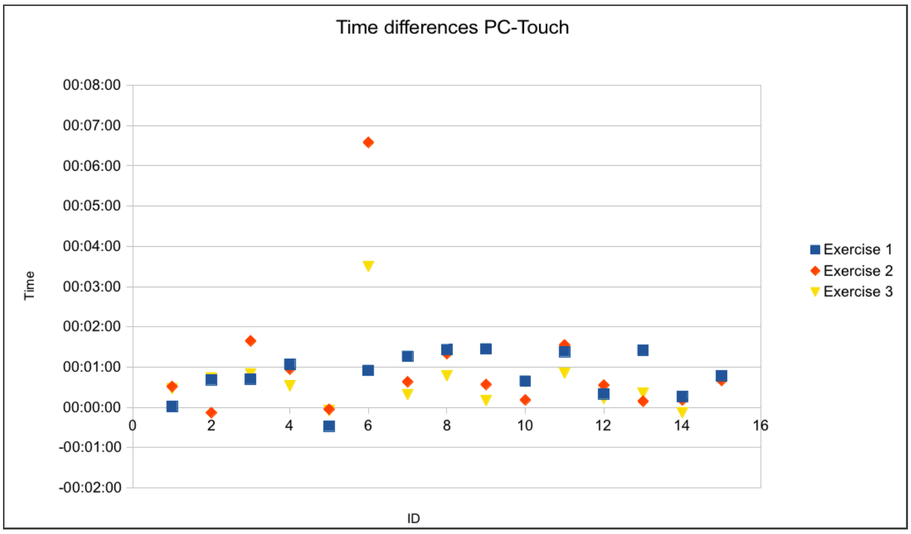

Figure 6. Time differences for all exercises with the experiment sequence *PC-Touch*.

As compared to keyboard and mouse, 53.3% of the participants showed faster and 26.7% slower learning results when learning an application with a touch screen.

3.3 Errors

Figures 7, 8 and 9 show a comparison of the error differences of the *Touch-PC* and the *PC-Touch* sequences. A majority of the participating students made fewer mistakes (higher differences) when using the application with a touch screen for the first time (Table 4).

Table 4. Error differences in percent for each exercise.

Exercise	Error Differences [%]
1	78,5
2	63,6
3	54,5

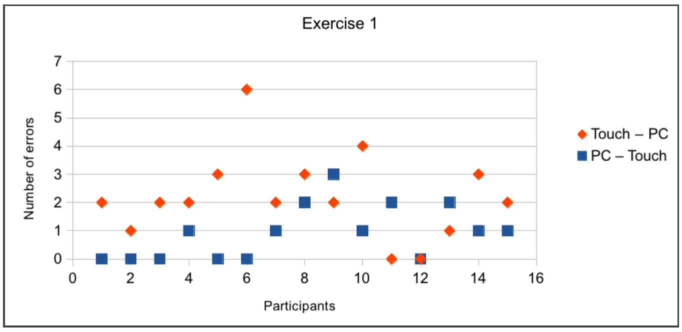

Figure 7. Comparison number of errors for exercise 1.

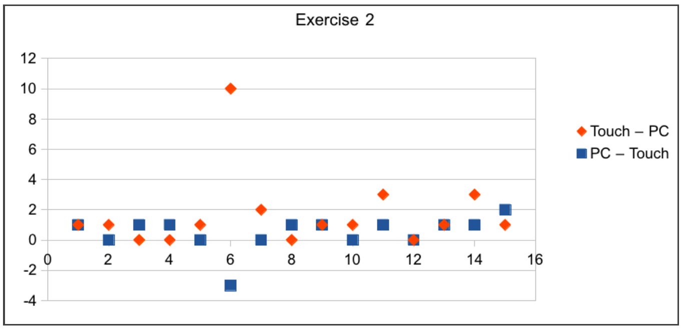

Figure 8. Comparison number of errors for exercise 2.

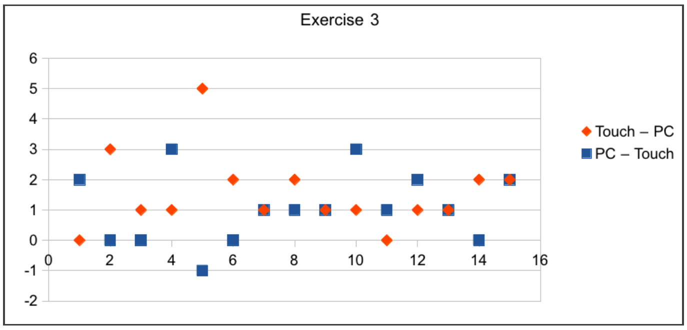

Figure 9. Comparison number of errors for exercise 3.

3.4 Input Devices

Gesture input is not effective in combination with common interface elements (sliders, buttons, lists). Navigation operations and events must be mapped to certain gestures otherwise navigation gets too complicated. The questionnaires show that touchscreen and personal computer are equally easy to use (each 50%). As to the *"fun factor"*, 65% of the participants enjoyed using the touch screen most and 35% the Kinect. No participant found the implementation of an information terminal with keyboard and mouse input interesting.

4. CONCLUSION

Curiosity is a strong motivator for learning new applications. The presented usability study revealed a number of implications for improving the work done so far. The integration of gesture input is not sufficient enough at the current development state. New implementation concepts are needed (e.g., map all navigation operations directly to certain gestures). Although some measurements indicated that gesture input might be an alternative to touchscreens and conventional input devices in future applications, the results were not considered. The gesture input implementation was not sufficient for the given use case. Given the learning performance and participant feedback, the touch screen appears to be the current information terminal device of choice. A prototype is implemented at the Department of Building Physics and Building Ecology (Figure 10).

As mentioned at the outset, building information terminals are used frequently and need to provide a good use experience. If the application or input method were not easy and understandable, users would be reluctant to spend time to learn it. Gesture input must be optimized and simplified to offer an alternative to touch and keyboard input. This includes an overall simplification of the application layout. Too complex workflows have to be simplified. One example is the interaction between modules. Currently, a user must move the cursor over a menu item to open a new module. In the future, offering the most relevant choices in a context menu will replace this practice. The present research is a first step to compare the learning implications of various input methods. It also shows limitations of conventional user interface layouts when multiple user input devices are supported. Gesture input support will be improved and included in future studies. Moreover, efforts will be made to extent the number and background of the participants, conduct more long-term experiments, and perform a more detailed statistical analysis of the results.

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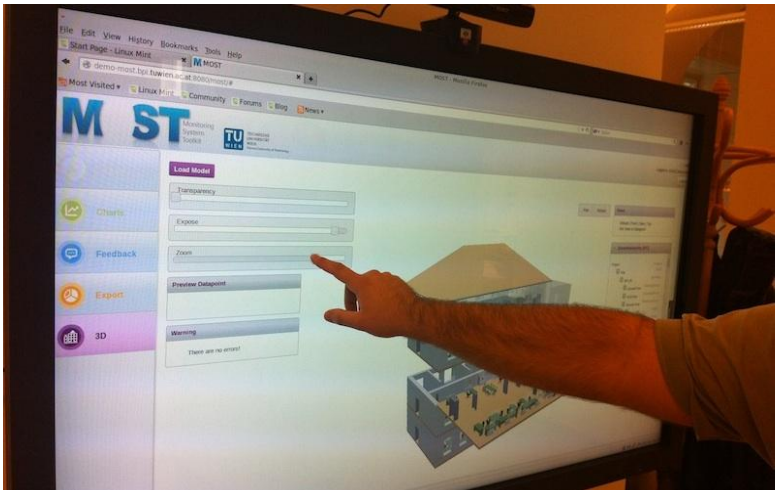

Figure 10. Final building information terminal implementation.

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