OHS Practitioners' Application of CAD-tools as Medium for Participatory Design;

Facilitating the Projection of Office-layouts

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FHVs användning av CAD-verktyg som medium för participativ design;

Stöd vid projektering av kontorslayouter

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ABSTRACT

When a company creates, rebuilds or develops new or existing workplace facilitates, research has shown such phases are of the most crucial and influential for creating healthy and effective workplaces. To include ergonomic principles in the early planning stages have proven to result in reduced expenses, and an increased ability to make influential contributions. Practitioners of Occupational Health Services (OHS) possess unique knowledge and expertise in the area, thus have potential to be a tremendous resource during the planning and projection of workspace design projects. Encouraging a participatory approach, OHS practitioners are valuable collaborators with end-users and Architects alike. In this study, three-dimensional CAD-tools were explored in order to provide OHS practitioners with methods and tools that enhance their ability to communicate workspace proposals to end-users of new or renewed office environments. Following an exploration process, a proposed design tool; SketchUp, was preceded for Usability testing. Results of the study indicated a considerable degree of applicability to OHS practitioners, despite an expressed desire for a simpler, more learnable interface. The software was believed to facilitate in the process of visualizing and communicating workspace proposals by increasing end-users understanding of the new work environment, including an enhanced ability to relate to and communicate with Architects.

SAMMANFATTNING

Forskning har visat att de faser där ett företag skapar, ombygger eller utvecklar nye eller befintliga arbetsplatser är av de mest avgörande och inflytelserika för att skapa hälsosamma och effektiva arbetsplatser. Att inkludera ergonomiska principer i ett tidigt skede av planeringen har visat sig leda till minskade kostnader och en ökad förmåga att göra inflytelserika bidrag. Utövare inom företagshälsovården (FHV) har en unik kunskap och kompetens inom området, och har därmed potential att vara en enorm resurs under projekteringen av designprojekt. Med ett tillvägagångssätt som uppmuntrar till delaktighet, anses utövare inom FHV vara värdefulla samarbetspartners med både slutanvändare och Arkitekter. I denna studie utforskades tredimensionella CAD-verktyg i syfte att tillhandahålla FHV med tillgång till metoder och verktyg som förbättrar deras förmåga att kommunicera ritningsförslag till slutanvändare av nya eller förnyade kontorsmiljöer. Efter faktainsamlingsfasen, utvärderades designverktyget SketchUp genom användbarhetstester. Resultaten av studien visade till en betydande grad av användbarhet till utövare inom FHV, trots en utryckt önskan om ett enklare, mer lättlärt gränssnitt. Programvaran ansågs underlätta i processen att visualisera och kommunicera ritningsförslag genom att öka slutanvändarnas förståelse av den nya arbetsmiljön, inkluderad en förbättrad förmåga att relatera till och kommunicera med Arkitekter.

Index words

CAD. OHS practitioners. Participatory design. Office-layout. Visualization. SketchUp.

Table of Contents

1.0 Introduction

This study is part of a Masters program of Ergonomics: Human, Technology, Organization, and caters to the audience and subject area of Human Factors and Ergonomics. The study is based on an ongoing project at KTH concerning OHS practices' involvement in workspace planning, and its aim is to assist KTH researchers in identifying applicable tools to facilitate in the process.

1.1 Background and Problem-description

The importance of including ergonomic principles in the early stages of the planning process of new or renewed workplaces is well documented (Eklund and Daniellou, 1991; Seim and Broberg, 2009; Antonsson et al., 2011). The designs of technical systems and products, facility layouts and workstations matching clients' needs, are examples of crucial factors often determinants to the working conditions and the occupational health and well being of the workers (Bohgard et al., 2010). Occupational Health Services (OHS) play an important role in preventing occupational injuries by working proactive while increasing the awareness and appliance of ergonomic principles within workplaces (Arbetsmiljöverket, 2011; LO, 2013). OHS practices generally possess a broad competency within the occupational health and safety discipline, reflecting their multi-professional profiles (Företagshälsor, 2013). Today, workplaces are by law required to collaborate with OHS in cases where they themselves are lacking the competence to satisfy the law and regulations listed in the Swedish Work Environment Act, paragraph 12§ (Arbetsmiljöverket, 2015). The paragraphs clearly draw connections between the physical environment and employees' health and safety, and demands that the necessary steps are taken to prevent any risk related to poor working conditions in this regard. This is also true for the planning of new constructions of occupational buildings (The Swedish Work Environment Act, Paragraph 6 & 7§).

During the process a company creates a new workplace facility, rebuilds their workplace facility or develops their existing facilities by acquisition of new equipment, research is showing such phases are of the most crucial and influential for creating healthy and effective workplaces (Seim and Broberg, 2009). Including ergonomic principles in the early stages of the planning have proven to result in reduced expenses in the implementation of such measures, and an increased ability to make influential contributions (Seim and Broberg, 2009; Hendrick, 2008). When applied late, and a mismatch between employees needs and the work environment is undeniably evident, making the necessary changes to solve the issues can be a much more complex and costly process (Hendrick 2008, Falck & Rosenqvist 2012). Hence, the OHS practitioners' involvement with workspace design, in collaboration with designers and the clients is an important step in the planning and designing of new or renewed facilities. (Seim and Broberg, 2009; Antonsson, et al., 2011). Unfortunately, OHS practitioners are often not included in this step, partly due to employers' lack of knowledge and confidence in that OHS can contribute in the area with profitability. Many employers seem unaware of OHS expertise expanding beyond single individuals (Antonsson et al., 2011). This stresses the importance of OHS being capable of providing attractive and effective services expanding the perspective to include the whole organization. Moreover, more research is needed aiming at increasing OHS' competency and access to methods and tools that enhance their ability to systematically contribute to proactive improvements (Seim and Broberg, 2009; Antonsson et al., 2011) Thus, in order to provide knowledge and support needed by OHS practitioners, researchers at the Royal Institute of Technology have initiated a project concerning the OHS' involvement in the planning of new occupational layouts (Eklund, 2013). Throughout the planning phase of new or renewed constructions, it is a desire that the OHS serve as a link between the company and the designers, providing input to both parties (Antonsson, et al., 2011; Seim and Broberg, 2009). This way, occupational health and safety aspects are included from the beginning, while involving the most important clients; the company and the employees themselves, enabling what Zandin (2001) refers to as a *participatory-approach*. Upon receiving the drawing proposal or blueprints from Architects, researchers have suggested that the OHS acquire the tools that provide a translation and clear visualization of the occupational layouts to the company's employees and management (Eklund, 2013; Rolfö, 2015). The fact that workspace proposals are frequently presented as two-dimensional drawings, present some challenges particularly for people outside the design-profession, who may be struggling to fully comprehend such drawings in detail (Zandin, 2001). The goal of a participatory approach is involving the clients actually affected by the changes, who are experts of their own work procedures and desires (Zandin, 2001). An ideal workspace proposal could enable this participatory process, by providing a clear visualization in which distinctly communicates the end-results of the changes to the users affected. As a result, this enhances the users' ability to influence their future work environment (Zandin, 2001), while providing a communicative platform for the OHS to discuss and visualize ergonomic issues and solutions.

3-D Visualization to Enhance a Participative Approach

Visualization techniques, particularly three-dimensional visualization, are quickly growing in popularity. It is appreciated as an effective communicative medium for intuitive spatial representation of an environment, model or space (Zandin, 2001; Johansson et al., 2013; Hayek, 2011). Several visualization techniques related to workspace-design exist today electronically and physically. These include simulation and animation, Virtual Reality Lab, Digital Human Modeling, full-scale modeling and prototypes, 3D print as well as other computerized drawing-tools recognized under the umbrella-term "computer-aided design" (CAD) (Schoonmaker, 2003; Schneiderman and Plaisant, 2010; Johansson et al., 2013). CAD has risen in popularity since decades, replacing some of the more manual techniques in response to the increasing digitization and globalization of design projects (Ibrahim and Rahimian, 2010; Schoonmaker, 2003). CAD not only facilitated communication between designers across countries and continents, but with its choice of two and three-dimensional methods proved an excellent medium for building and visualizing a variety of different architectural designs, workspace design included. With endless functionalities and features that let the user build, manipulate, navigate and dynamically visualize personalized environments or models, it attracts many kinds of different users (Schoonmaker, 2003). Respondents in the ongoing study of Holm (2015) showed that roughly 23.5% of the OHS practitioners believed that easily navigated visualization tools could facilitate in the involvement in the planning and design of work environments or technical equipment in new construction, renovations and extensions. However, CAD as a contributive aid to Ergonomists during workplace design is not a new proposal. Already in 1988, authors recognized CAD as *an Enhancement of the Ergonomist's Role in the Design Process* (Fallon and Dillon, 1988). Other authors even go as far as to say it is essential (Zandin, 2001).

OHS' Workspace Projects

An ongoing study including OHS practitioners showed that roughly 46% had been involved several times in the planning and design of work environments or technical equipment (Holm and Rolfö, 2015). Out of all work environments, projects involving offices were of the most common (Holm and Rolfö, 2015). Offices are a highly researched topic concerning ergonomics and risk factors, and office workers are seen to increase in number in both the private and public sector (Czaja, 1987 cited in Margaritis and Marmaras, 2007). The number of office workers is expected to further increase in the future; given the spreading of information technology (Margaritis and Marmaras, 2007), and other automated technology. For these reasons partly, offices are also the primary target in this thesis.

1.2 Purpose and Thesis Question

The purpose of this study is to identify existing three-dimensional computerized design-tools applicable for office-layouts, that reflect the level of usability required for the more inexperienced users of computer aided design (CAD). The study seeks to concretize to which degree any of the identified tools are applicable tool(s) to be used by OHS practitioners, as a means of visualizing and communicating blueprint proposals to end-users of new or renewed office facilities.

The aim of the tool(s) is for it to be a communicative medium encouraging a *participative* approach during the planning stages of new or renewed office-facilities. To concretize this, the study is seeking to answer the following questions:

1) Which computerized design tools for facility-layout exist on the market that attains a level of usability required for the inexperienced users of computer aided design?

2 a) To which degree is any of the identified design tools applicable to OHS practitioners
and…

b) How can they facilitate the process of visualizing and communicating blueprints of future offices?

1.3 Delimitations

The time (15hp) limits the amount of testing possible within the given time frame. Hence, the following study is not a comprehensive study of CAD tools; rather, its aim is to illuminate an awareness of the importance of the subject matter.

This study seeks to cover certain theories about CAD, but does not go in depth to explain about learning CAD-software. To gain this knowledge, the reader is referred to learning materials of CAD or other professional courses.

1.4 Disposition

This paper is best read chronologically, as some sections are based on previous sections. Following the theoretical section, the method, result, discussion and conclusions are proceeded in this order. The result section being the most comprehensive, results are divided into two separate headings.

2.0 Theoretical Background

The following chapter defines a Human-technology system particularly suitable for inexperienced users of a screen-based interface. This includes Usability and novice behavior, including some common methods of importance to the subject matter. Following this, a description is made of the potential user population, as well as common tasks related to workplace design. At last, workplace design is explained in terms of participatory design, which further explains CAD's role and ways it can contribute to the process.

2.1 Human-Technology Systems

The process of matching a computerized program with users is a typical example of what can be referred to as a *Human-Technology system*. A Human-Technology system concerns interactions that occur between the user and a technical system; e.g. a computer-software. (Osvalder and Ulfvengren, 2010).

The user (the person that interacts with the system) of a Human-Technology system controls the technology and makes decisions about future actions based on the status of the interface. The *interface* refers to displays and instruments that communicates and present information about the systems' status to the user. The human brain perceives this information through their senses, process and interprets it. The user further manages the system via controls i.e. keyboards, mouse devices, buttons and/or joysticks. The system further processes and encodes this control-data, which results in a new status, and so on (see figure 2.1) (Osvalder and Ulfvengren, 2010).

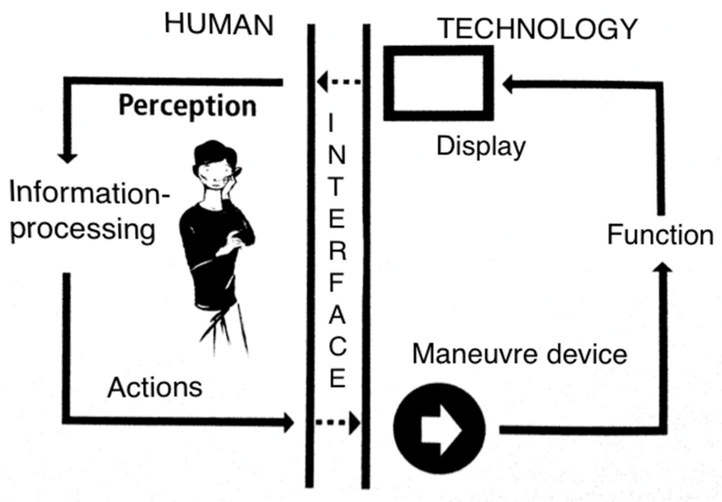


Figure 2.1) A Human-Technology model illustrating the interactive cycle of information-exchange between the user and the technology (Osvalder and Ulfvengren, 2010).

The purpose of a Human-Technology system is the ability to perform specific tasks. This is the intended outcome of an interaction that is useable (Osvalder and Ulfvengren, 2010).

2.1.1 Usability

"*The objective of designing and evaluating visual display terminals for usability is to enable users to achieve goals and meet needs in a particular context of use***"** *(ISO, 1998).*

CAD systems have continuously developed and advanced, and so has the Internet and computer systems' capability to deal with the increasing demands of CAD and other advanced software. However, advancements in software come with a cost, it is also more demanding for the users (Schoonmaker, 2003). Computer-use is often linked with frustration, worry and prone to error. Luckily, since the new emerging science of *human-computer interaction,* user focused and user-friendly interfaces are becoming more dominating in the field of computer-science (Schneiderman and Plaisant 2010). Combining methods from experimental psychology, integrated with industries like graphic design, human factors engineering and information architecture, the focus on interface *usability* has contributed to many benefits to the users.

The International Standards Association defined usability as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 1998). *Effectiveness*, according to Jordan (2002, pp.5) is "the extent to which a goal, or task, is achieved". *Efficiency,* is defined as the amount of effort that is required to accomplish a goal, while the term *Satisfaction* is described as the level of comfort that the user is feeling when using a product, as well as how acceptable the product is to users as a means of achieving their goals (Jordan, 2002).

Schneiderman and Plaisant (2010) and Jordan (2002) link the usability terms to more practical evaluations:

Effectiveness – This term can be measured by evaluating whether or not the user is successful with performing the intended task. In other words, effectiveness is directly concerned with the ability to achieve the tasks intended within the particular system. As one task can have several subtasks, the measurement may involve counting the number of successful or unsuccessful task-performances.

Effectiveness can also be linked to the quality of the outcome. Simply achieving tasks may not be sufficient if the quality of the end-result is not reaching the expected outcome.

Efficiency – the term can be understood as the time and effort required in performing tasks. The less steps and time spent to complete tasks, the higher the efficiency. For example, *Speed of performance* concerns the amount of time it takes to achieve a desired task, once familiar with the interface. If something that should be straightforward cannot be performed at a decent speed, the question should be asked as to why. Furthermore, if having to consult a help-manual to complete most tasks this requires both effort and time. Although a system providing informative manuals are helpful, they should not be required to be used extensively and certainly should not be replacing good and intuitive design.

Other terms related to efficiency are *Learnability* and *Memorability*. These terms are concerned with the degree in which methods to achieve tasks are easily memorable, requiring little effort and training in order to reach a competent level of performance. For instance, in terms of computer software, recognition-based interfaces are believed to be *learnable* as it prompts the user with visual clues rather than requiring the user to memorize and recall information in the interface.

Another crucial measure for efficiency is the *error-rate*. The amount of effort required to perform a task can be directly linked to the amount of errors a user makes. Errors can be further categorized based on the severity and consequence of the error. An error can be minor; immediately noticed and recoverable, or more major; whereas the error is noticeable and reversible, but with a higher cost (i.e. a higher amount of effort and time spent on noticing and correcting the error). Errors worse than this are either *fatal*; the user is unable to complete their task due to an inability to reverse errors made, or *catastrophic*; the errors not only inhibit the user in performing the tasks intended but the errors create other problems (i.e. accidently deleting a file). Thus, error prevention is about helping the user recognize, diagnose and recover from errors made, within a timely and effortless manner and without 'catastrophic' consequences.

Satisfaction – Satisfaction is a subjective measure, and concerns the user's experience with the system, whether they look back at the application with a positive or negative attitude. User-feedback may be obtained in terms of satisfaction scales, or by open-ended questions concerning different aspects of the interface (Jordan 2002, Schneiderman and Plaisant 2010).

2.1.2 Skill-based Behavior

When exploring a match or mismatch in a human-technology interaction, being able to anticipate the skill-level of a particular user-group is of high significance (Osvalder and Ulfvengren, 2010). This is important particularly because the degree of personal competency may influence the level of usability (effectiveness, efficiency and satisfaction) that the user experiences in their interaction with the system interface. When interacting with an interface, the way that users react, act and behave can be directly linked to their level of expertise with the particular system or task (Wickens et al., 2004). Unsurprisingly, the less experienced and familiar one is with a task, the higher are the demands on cognitive resources. A novice user has the disadvantage of having fewer experiences to rely on to help process sensory inputs from the environment. The less experience in terms of relevant stored information in long-term memory functions, the more reliant one is on the information available in the environment e.g. in an interface. This, in turn, requires extra effort from attentive resources, working-memory or short-term memory functions. Due to the attentional and working-memory's limited capacity, the ability to focus on additional incoming stimuli is strongly restricted. Hence, for an interface, the following may apply:

1.) The information and stimuli available may compensate for the lack of experience drawn upon from long-term memory.
2.) Previous experience or information stored in long-term memory may compensate for the lack of stimuli and information available (in the interface).

2.1.3 Usability for the Inexperienced Users

As indicated above, novice users face particular needs. When designing for the novice, many of the same usability features previously mentioned apply, such as ease of learning, low reliance on memory, informative diagnostic feedback for error prevention, etc. (Schneiderman and Plaisant, 2010). The question of user manuals is more controversial, as informative user-manuals, video-demonstrations and tutorials can be valuable and effective, yet the over-use of these may reflect poor usability in the rest of the interface (Schneiderman and Plaisant, 2010; Jordan, 2002). Another challenge with online user-manuals' is their accessibility; they should be easily searchable while not interfering with the tasks. Thus, usability principles also apply to help-sections.

Some degree of anxiety is quite normal when interacting with a computer interface for the first time; therefore gaining the users confidence in being able to use the system is important. This can be achieved by restricting the number of actions required to perform simple tasks successfully, as well as restricting the vocabulary to include only a small amount of familiar, consistently used terms relevant for the interface (Schneiderman and Plaisant, 2010). The novice user will also benefit from informative feedback about their task-performance, partly because poor feedback diminishes learning (Wickens et al., 2004). Moreover, given the high memory-load often experienced by these users, it is important to replace memory functions with visual perceptive information, such as *recognition* rather than *recall*. Recognition-based interfaces are graphical representations, i.e. menus, groups of icons or direct manipulative objects. They are based on the idea that users can recognize the action required rather than having to recall text commands. But a menu alone may not be sufficient if the menu-selections do not include clear, comprehensive and understandable terminology. This principle may also relate to *conceptual models*, which are perceptive information representative to real world scenarios such as familiar metaphors or language that draws on the user's experience in the real world. The familiarities of the conceptual models help the user recognize functions of an interface, despite not being experienced with the particular software (Wickens et al., 2004).

Schneiderman and Plaisant (2010) raise another issue. Reaching a desirable level of functionality while reflecting a level of simplicity for the novice is demanding for any software. A solution for this may be so-called *multi-layered design*, whereas novices are only being taught and presented with parts of the existing tools and options, in which reduces their risk of error and simplifies task-performance. Once the user has reached a higher level of competency, their desire for greater functionality are likely to increase, to which more functions and features can be made available (Schneiderman and Plaisant, 2010).

2.1.4 Usability Testing and Decision Matrices

The above-mentioned criteria together with the usability evaluations form a set of practical metrics usable for evaluating the degree of *fit* between the novice users and the system applicable. So-called *usability testing* is describing a process where users are purposefully set to interact with a system, to identify any usability design flaws overlooked by that of the evaluators or designers (Wickens et al., 2004). Usability testing is based on measurements of so-called usability *metrics*. The selection of usability metrics or criteria within Human Factors and Human Computer Interaction can be complex due to the vast amount of design-principles and guidelines available in literature. The increasing demand on user-friendly design have resulted in a numerous of models and theories (Schneiderman and Plaisant, 2010). Examples include national and international standards such as ISO (International Organization for Standardization), WCAG (Web Content Accessibility Guidelines), Gulf of Evaluation by Norman (2013), The Eight Golden Rules (Schneiderman and Plaisant, 2010), among many other theories and versions of theories (Osvalder and Ulfvengren, 2010; Schneiderman and Plaisant, 2010; WRC, 2008; ISO, 1998). Since it is virtually impossible to consider all of the existing design principles simultaneously, a process of prioritization is crucial (Osvalder and Ulfvengren, 2010). Yet even once a set of principles is decided upon, they can be given a higher or lower priority based on the desirable outcome (Schneiderman and Plaisant, 2010).

When it comes to the actual selection and comparison of *concepts* (in this case drawing tools), the process of *Concept selections* can be very challenging involving complicated decision-making, prioritizations and narrowing of concepts (Ulrich and Eppinger, 2008). Whether it is a conscious effort or not, a team or a person choosing a concept is always using some method(s) to exclude and conclude. (Ulrich and Eppinger, 2008). A structured method for concept selection is recommendable, since it helps maintain objectivity during the concept selection stages, as well as provides a rationale behind concept decisions (Ulrich and Eppinger, 2008).

An example of a structured method is decision matrices. Decision-matrices facilitate the decision-making process by rating and ranking each concept with pre-specified selection criteria's. The methods can be divided into two phases; *the screening,* whereas concepts are rated, ranked and selected based on the selection criteria's only, and the *scoring*, whereas the same steps apply but through a somewhat more thorough analysis (Ulrich and Eppinger, 2008).

Concept Screening and Scoring Matrix

When using ***concept screening*** (also commonly known as *Pugh concept selection*), a list of concepts and criteria's are entered into a matrix (see figure 4.2.6). The key features of a concept may be further described in written and/or graphical form. Selection criteria are typically based on the user need as well as any other important stakeholders. At this point a *reference* concept; with the function of a benchmark, is chosen. All other concepts will be compared to this reference. The reference is often chosen based on familiarity, quality, availability, and are to be as representative as possible for the desired function and product.

The concepts are further rated and given a score of *better than* (+), *same as* (0), alternatively *worse than* (-) in comparison to the reference, which is entered into each column. At the end of the scoring, the number of *better than, same as,* and *worse than* is calculated and entered into the *Sum* column. A Net Score is calculated by subtracting the total of *worse than* from the total of *better than* ratings. From these sums, it is then possible to rank the concepts based on all the scorings (Ulrich and Eppinger, 2008).

A concept scoring matrix is applied in cases that the *concept screening matrix* is seen as insufficient for the selection-process, given the scoring and weighting of concepts may provide a more detailed and thorough evaluation of the concepts. The process resembles the concept screening in that desirable concepts and criteria's are entered into the matrix. One concept may also here be set as a comparable reference; however, scorings can also be achieved by not defining any reference. The main difference in this method is that the evaluator(s) are to weight the importance of each of the selection criteria, by adding a value either in percentage or in value. Another difference to the previous matrix is that the concepts are rated based on a finer scale, e.g. 1 to 5. In this instance the rating number are linked to a description e.g. *1: Much worse than reference,* or *5: Much better than reference.* The total score of each concept is then calculated by multiplying the scores by the weight of the criteria, each total score reflecting the sum of the weighted scores (Ulrich and Eppinger, 2008). Refer to section 5.3 for a precise example.

2.2 Interaction Analysis

Methods in an Interaction analysis, described by Osvalder et al. (2010), evaluate and identify usability and use errors in a human-technology interaction. The methods are particularly valuable for evaluating technical products with a screen-based interface, whereas a step-by-step procedure is required to achieve a task. Results from an interaction analysis can illuminate potential faults in a system that is usable for comparing, improving or otherwise predicting the system-status. One or several evaluators with the necessary knowledge of e.g. interface-design and cognitive ergonomics can perform an interaction analysis. The following steps and procedures may be applicable as part of an interaction analysis:

1) A definition of the evaluation; an establishment of framework for the product to be evaluated, its use, potential users and environment.

2) A description of the human-technology system through a thorough description of each of the components parts, such as the user, environment, tasks and interface of the product. *User-profile* and *Hierarchical task analysis* (HTA) are applicable methods for this, as explained later on.

3) Further analysis of the steps and potential usability errors.

4) A summary of the results (Osvalder et al., 2010).

2.2.1 User Profiles

Creating user profiles is one of the recommended steps in the Interaction analysis for reaching an understanding of the Human-Technology system. A user-profile can be applied on a targeted group or of one or several individual users (Osvalder et al., 2010).

The profile concerns characteristics of the user-population, such as their background, usage, type of interaction and activities, goals and motives with the product, among other attributes relevant to the study. The purpose of a user-profile is to assess factors that may influence the interaction with the system. The same authors stress the importance of classifying user types into four roles: primary, secondary, side-user and co-user. The differences between the various roles are their level of interaction with the actual system; whether it is directly or indirectly, whether the user is involved in its primary or secondary functions, or is simply affected by its presence.

2.2.2 Hierarchical Task Analysis (HTA)

A *Hierarchical task analysis* is a widely used method to structure and reach an understanding of the task(s) to be performed within a system (Osvalder et al., 2010; Schneiderman and Plaisant, 2010). The analysis includes describing in detail the steps to be performed by the user in order to complete a task, i.e. reaching a specific goal (refer to HTA-analysis under section 4.2.4). The HTA procedure begins by identifying the overall goal of the tasks to be performed. Next, the goal is divided into sub-goals, which are steps necessary in order to reach the main goal. These sub-goals can, if needed, be further divided into so-called *operations*. *Operations* are the lowest level of the HTA-chart and may include two types of information: 1) the goal of the operation and, 2) the action to be performed. The required information can be collected through observations, user interviews, instructions, manuals, etc. (Osvalder et al., 2010).

2.3 The OHS (Potential Users)

Occupational Health Services (OHS) today consist of specialists with expert-knowledge within areas of work environment & health, preventive healthcare and rehabilitation (Sveriges Företagshälsor, 2012). They provide services at an individual, group- and organizational level and their overall aim is to detect, prevent and decrease occupational health and safety risks in any given workplace (Arbetsmiljöverket, 2011). OHS practices work towards exploring the connections between the work environment, and the organization's productivity and health. With a focus on client-engagement and collaboration the potential for sustainable, positive changes are probable (Sveriges Företagshälsor, 2013). Given its broad focus, various competencies are required e.g. within work organization, occupational hygiene, behavioral science, ergonomics, medicine, rehabilitation and technology (Arbetsmiljöverket, 2011). In order to meet these demands OHS practices often consist of multidisciplinary teams of professionals with different backgrounds, with a joint competency in occupational health and safety. (SOU, 2011). While some practices work internally as part of particular companies, most commonly they are part of external organizations and accessible to a variety of different industries (Sveriges Företagshälsor, 2012).

A diagram from Sveriges Företagshälsor (2014) presents a rough distribution of the different work areas that OHS practices today are commonly involved in (figure 2.2):

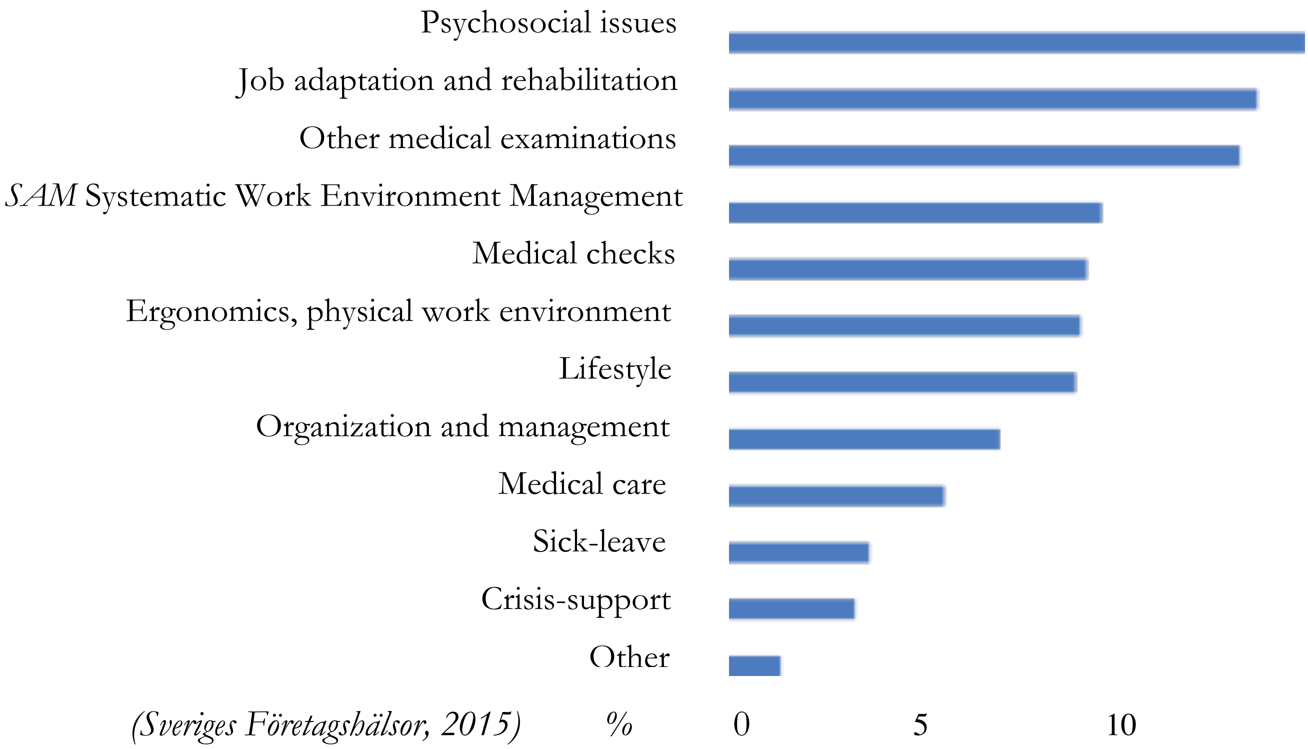


Figure 2.2) A diagram showing the estimated distribution of work tasks OHS practices are involved with in 2015.

2.3.1 Workspace Design in Relation to Office Layouts

It was previously pointed out that the design and layout of work buildings can have an effect on employees' health, job satisfaction and job performance (Bohgard et al., 2010).

As seen in the diagram, ergonomics and the physical work environment are not uncommon work areas among OHS practitioners, and in particular among Safety-engineers and Ergonomists (SOU, 2011). Although OHS practitioners may not be commonly thought of as workspace designers, OHS practitioners hold a unique knowledge and expertise in the area from the perspective of occupational health and safety (Seim and Broberg, 2009). The following description of *ergonomics* from the International Ergonomics Association, clearly states *design* as a central focus:

"Practitioners of ergonomics and ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people" (IEA, 2015).

Evidently, ergonomics is concerned with the *design of* products, environments and systems to fit the potential user. Given the different kinds of interactions and complexity of such components, ergonomic design involves holistic, system-approaches that are concerned with interactions involving the human, the technology and the organization (Bohgard et al., 2010). Below is a more thorough description of the many areas in which OHS practitioners may contribute during the design of office-layouts.

Offices

Offices are prone to many occupational health and safety challenges. While some of these have received a lot of attention in media and in research (Berner and Jacobs, 2002; Bohr, 2000), others are less known. Office-work is usually associated with prolonged sitting and often involves work in front of visual displays. A lot of the health promotion thus is about stimulating to frequent movements while optimizing comfortable and healthy work positions (Arbetsmiljöverket, 2015). This can be achieved through well thought out placements of rooms, functions and workstations that naturally promotes activity as part of the work routines. Choices about furniture need to be based on sound reasoning, with the goal of being suitable to both the characteristics of the work-tasks and the individual (Arbetsmiljöverket, 2015; Hendrick, 2008). For visual displays, lighting and the positioning of desks can impact the degree of distraction experienced by the worker due to glare and reflections in the environment (Margaritis and Marmaras, 2007; Arbetsmiljöverket, 2015). Lighting; both interior and daylight is important for numerous reasons, such as the experience of comfort and safety, the ability to move around and perform work tasks safely and efficiently, not to mention daylights' healthy biological effects on the human body (Arbetsmiljöverket, 2015; Hendrick, 2008).
Office environments are prone to noise; particularly common in open plan

offices where the sources of noise are from people naturally talking and working in the same space. While certain noise may be inevitable, noise can be reduced by making simple adjustments in the environments such as through choosing sound absorbing materials and partitions, being wary about the placements of sound-disturbing equipment and functions, as well as the placements of individual workers based on their need for communication or seclusion (see figure 2.3).

Offices are also vulnerable to ventilation annoyances, uncomfortable heat, or allergy provoking environmental issues. These are further influenced by the placements of calorific equipment, materials and furniture arrangements including the use of blinds and shutters for the controlling of heat. Other aspects directly associated with workspaces are the design and size of floor surfaces, rooms' height, clearances, as well as the accessibility and the arrangement of evacuation routes and exits (Marmaras and Nathanael, 2006 cited in Margaritis and Marmaras, 2007; Arbetsmiljöverket, 2015).

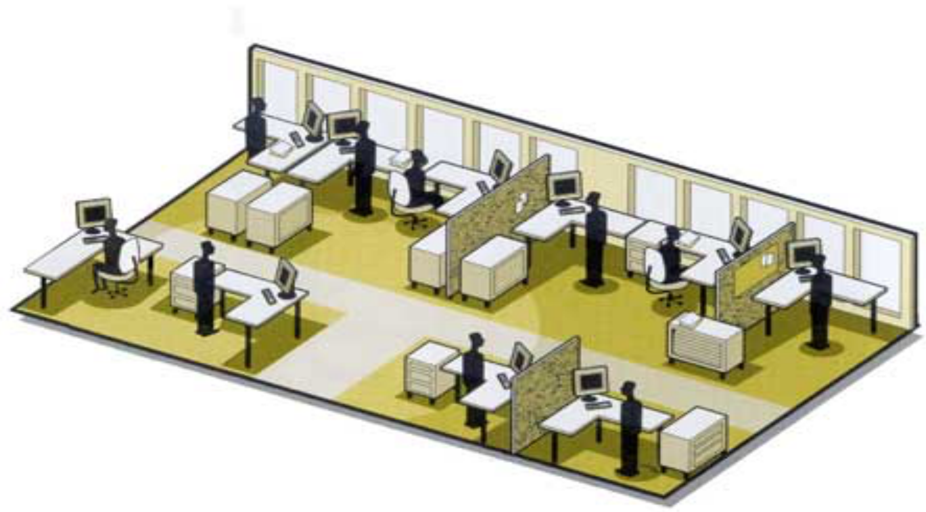


Figure 2.3) Example of an open plan office (Danielsson, 2008), and alternatives of office solutions such as standing and seated workstations, partitions for increased privacy and noise reduction, placements of visual displays in relation to windows, etc.

2.4 Participatory Design and Computer-aided Design (CAD)

The magnitude and complexity of ergonomic design presents OHS practitioners with a considerable challenge: the collaboration with other important stakeholders. Bohgard et al. (2010) illustrates key operators, customer participation displayed at the top alongside designers and constructors. He emphasizes that customers, or more precisely the users, are considered crucial participants in all stages of the engineering process. Such a process is sometimes referred to as *participatory design*, or *participatory ergonomics*

(Zandin, 2001; Seim and Broberg, 2009). It draws together experts with specialized knowledge in a specific field such as ergonomics, with the inside knowledge and experience of the users. In the case of workplace-design, the primary users are the ones most affected by the changes, i.e. the companies' own employees (Zandin, 2001). Since understanding the users and the tasks to be performed within the system is such an essential part of workplace design and ergonomics (Bohgard et al., 2010; Zandin, 2001), this step should already be embedded in the design-process. Yet, Zandin (2001) indicates that it in reality is not so simple. Since traditional design-methods are often rushed and restricted by time limits, the final users are not consulted or at best informed at the last minute when any desirable changes are less amendable (Zandin, 2001; Hendrick, 2008). Even when ergonomic solutions are included, positive outcomes are inhibited. The lack of involvement and influence during the process may cause employees to resist the changes, uncertain about how to respond to the new environment (Zandin, 2001).

Another issue hindering a participatory approach is the ways in which information is presented to employees. Although many different participation methods for workplace design exist (Seim and Broberg, 2009), a majority of layout proposals are still being presented as traditional two-dimensional drawings (Zandin, 2001). This is not to say that two-dimensional interfaces aren't helpful, but for the purpose of facilitating non-designers in envisioning a work building, Zandin (2001) is suggesting more distinctive approaches. His proposition is to include three-dimensional computer visualization tools into the planning and design of workplaces. He outlines four steps for a successful participatory process during workplace design:

1. The project needs to be fully supported by management levels.
2. A smaller project-group should be formed, with representatives from different backgrounds e.g. engineering, manufacturing, and ergonomics. The group-members can be both internal and external.
3. Predominately, operators; employees well familiar with the work routines, should have an apparent role in the project group.
4. Everyone involved must be given opportunity to understand and comprehend the plan and details as well as the ability to influence. Specific emphasis is put on the planning, with the reasoning that thorough planning saves both time and cost in the end, despite appearing time-consuming and costly during the process. This step is where visualization tools, such as computerized three-dimensional representations, are best included.

Three-dimensional Visualization

Different authors emphasize several advantages and ways that three-dimensional visualization can enhance the participation required for the last-mentioned step (Hayek, 2011). Wissen et al. (2008 cited in Hayek, 2011) argues that 3-D visualization supports individual cognitive information processing such as the ability to extract relevant information out of its context. Hayek (2011) believes that visualization has communicative strengths particularly helpful during the early stages of planning, resulting in increased motivation while facilitating relevant information-exchange. Moreover, it is believed to trigger a high identification of a model, limiting the errors in interpreting (Hayek, 2011; Schoonmaker, 2003).

> *"3-D CAD can not be beaten. The intrinsic advantages of a complete geometric model of a product are simply too great". "Once a 3-D model exists, it can be interrogated, studied, analyzed, and sliced and diced in a way that not even a physical prototype can equal" (Schoonmaker, 2003, p.171).*

Visualization techniques for workplace design are many and applied for numerous reasons (Zandin, 2001; Johansson et al., 2013). Many of the techniques come under the term Computer-aided design, *CAD* (Zandin, 2001). CAD can basically refer to any computerized activity to create or modify two-dimensional or three-dimensional designs (Schoonmaker, 2003; Zandin, 2001; Techterms, 2014). It is spanning from the more simple drawings and sketches, designs and three-dimensional models, to layouts, design calculations and detailed technical drawings (Schoonmaker, 2003). Three-dimensional CAD consists of mathematical models that are capable of exact geometry (Schoonmaker, 2003). This means that one can resemble reality by building a model with exact dimensions as well as correct positioning within a given space. View-scales can be entered, showing the precise relationship between the model(s) in the computerized design drawing with the actual object(s) in real life to be documented. Distances between objects, lines, edges and surfaces are measureable. In more advanced software, the volume as well as the weight of a 3-D model can be calculated, given that sufficient details are included such as materials. The exact geometries created in the design can furthermore be manipulated; duplicated or scaled to smaller or larger sizes without losing its original structure. A model may also consist of several part-models that are designed together as a group, so-called *assemblies*. An example of this is a bicycle, which consists of several parts such as a seat, frame, forks and handlebars, front and rear wheel, etc. These parts are useful for creating and changing details and add extra flexibility to the design.

Once a design is built, the design can be rendered through visualization-tools such as *pan, zoom* and *rotate,* and display views from many different angles such as in the X- and Y-direction, and three rotating directions (X, Y and Z). The common views found in two-dimensional drawings; front, top and right can be visualized more or less simultaneously, without limiting the drawing to any particular views (See figure 2.4 and 2.5). For the sake of visualization, pointing devices such as mice or 3-D balls are a necessity, in conjunction with keys on a computer-keyboard (Schoonmaker, 2003). Yet, these techniques only cover some of the basic visualizations applicable in CAD. Many other visualization techniques are becoming compatible with CAD-designs, and may be used in conjunction as a means of complementation (Zandin, 2001).

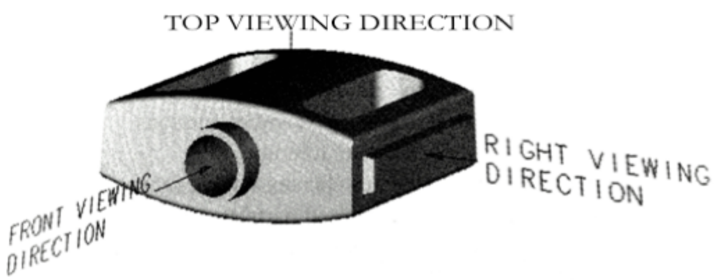


Figure 2.4) A three-dimensional model displaying some of the common viewing angles possible in 3-D CAD (Schoonmaker, 2003).

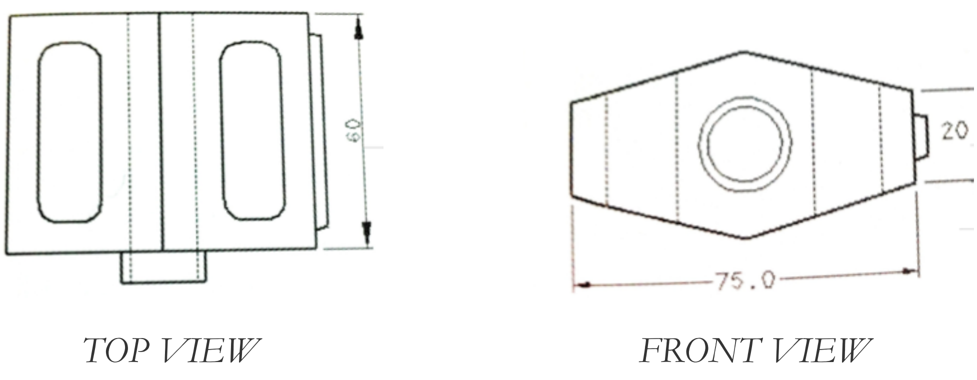


Figure 2.5) The ability to visualize from different viewing angles captures additional dimensions such as the depth (Top view), and the width and height (Front view) of an object (Schoonmaker, 2003).

The Application of CAD during Workplace Design

Evidently, the endless functionalities of 3-D CAD come with great advantages. Yet, understanding how CAD can be used for workplace design is an important component in the process of applying the benefits of 3-D CAD. Zandin (2001) emphasizes that during the planning-stage of any workplace changes, accessing drawings including the exact measurements, geometry and positions of spaces, equipment and furniture in the building is an important first step to achieve accuracy in the layout. One may include photographs or video-recordings of materials and equipment, while collecting information about activities taking place in each of the areas; the way that people act and move in their environments (Zandin, 2001; Tabak, 2008). Certainly, 2-D drawings play a big role in the creation of 3-D CAD since many 3-D CAD-software requires the sketching of 2-D geometry as a base prior to turning any model into a 3-D feature (Schoonmaker, 2003). Yet, it is up to the user to determine what 2-D geometry is needed for the specific 3-D model (Schoonmaker, 2003). For the purpose of saving time and storage-capacity, Zandin (2001) recommends designing "different environments for different purposes". For example, detailed and non-detailed environments serve different purposes. For an overview of an entire work building, it may be sufficient for equipment and furniture to be made rough, inspiring discussions about placements of departments and work-stations, the overall work-flow, exit routes, etc. Greater details might be preferred when emphasizing working techniques and procedures, heights of furniture or visual displays and the placement of equipment. During the visualization stage, emphasis should be on areas of particular importance, e.g. the area of the workplace that is facing the most changes (in the case that changes are made to an existing workplace). For effective visualization, Zandin (2001) stresses the importance of choosing a visualization view that matches the purpose. For example, when displaying the overall work building, a top-view (also referred to as *bird's-eye view*) provides the necessary outlook to achieve this purpose. However, for the more detailed work-environment where employees are to understand how an inside area is going to look like up-close, it is advised that the camera is set low, slightly below average eye-level, to achieve a realistic outlook.

Lastly, Zandin (2001) believes that an effective technique for both speeding up the workplace planning and increasing participation at this stage is to manipulate and create relevant changes directly onto the CAD-drawing, while involving the users. Yet, for this goal to be achieved, Zandin (2001) stresses that the software should not be so advanced that the practitioner is not able to handle the drawing-tool efficiently. If this isn't the case, the workshop risks getting the opposite effect e.g. become time-consuming, costly and decrease creativity. This is why choosing the right level visualization tool and

CAD-software plays a big role in the workplace planning.

Table 2.1: Explained terminology used in chapter 2.4.

TERMINOLOGY	
Geometry	*Representations of free-form curves, edges, surfaces, or volumes for any objects*
Surface	*A thin boundary defining an object's exterior*
Pan	*The ability to visualize a 3-D design model from different angles through moving in the X and Y-axis.*
View scales	*The dimensional relationship between the object or geometry shown in the 2-D drawing and the actual object being documented. E.g. in a 1:50 scale, 1mm on the drawing represents 50mm on the actual object (Schoonmaker, 2003).*
Rendering	*The calculations performed by a 3-D software' render engine in order to translate scenes from a mathematical approximation to a finalized 2D/3D image. The entire model's spatial, textural and lighting are combined, e.g. to determine the color value (Slick, 2015).*

3.0 Method

The following study is a qualitative evaluation study based on exploratory elements (Rolfö, 2015). The process consisted of identifying, exploring and evaluating a match between user-group(s) and tool-characteristics. The method was following the order of an *Interaction analysis* described in section 2.2. The data collection methods consisted of:

- Two open half-structured interviews with two professionals with significant experience and knowledge of OHS practices.
- Consultations about CAD, CAD-tools and the collaborations with Architects, through email- and telephone correspondence with Visualization and CAD-experts, User communities and program suppliers. These included a Researcher and two (Associate) Professors experienced in Visualization techniques, two CAD-experts, an Architect and a 3-D Developer *(Attachment 1)*.
- Usability-tests with potential users of the software: Four separate sessions, six participants.

3.1 Data Collection and Background Research

3.1.1 Identifying the Product, its Use and the Users

The first steps in the process consisted of identifying drawing tools existing on the market. For the tools to be relevant however, specific information needed to be collected regarding its use and its potential users. The initial contact with KTH researchers helped identify the overall purpose and use of the tool. Theories of participatory design further shaped it. The OHS professional profiles helped pinpoint crucial tasks performed by OHS practitioners during workplace-design. However, the user-profiles were still inadequate, and a greater understanding needed to be gained of the characteristics sought for in a design-software. This meant collecting information about the representative users and their user-profiles, analyzing the tasks to be performed within the system, and exploring evaluation criteria's relevant for reaching the goal of usability necessary for the particular users.

3.1.2 Qualitative Interviews

To cover the above step, two qualitative open half-structured interviews were performed on two respondents with significant experience and knowledge of the OHS. The open half-structured interviews were chosen to give the respondents a chance to provide fulfilling answers while still being relevant to the subject matter.

The selection criteria were based on a strategic selection reflecting an information-need of the subject matter. Both respondents had worked as OHS practitioners for a number of years, and were experienced with workplace design, including collaborating with Architects. The respondents were asked a number of open-ended questions regarding the potential user-groups and their user-profiles, tasks performed during workplace design, potential tasks to be performed within a computerized design-tool, etc. *(appendix 2).* The first interview was performed via Skype, whereas the second was performed in-person at the practitioner's workplace. Both interviews were tape-recorded, which the participants gave their consent to. The prepared interview time was set to about 1.5 hours. In reality, the interviews lasted between one to two hours.

3.1.3 The Search for Design-tools

The process of identifying suitable design tools was continuous but followed a specific procedure. Firstly, tools were explored through online databases such as Art & Architecture Complete, Ergonomics Abstracts and Access Engineering, in addition to more traditional information seeking search-engines like Google Scholar, YouTube and Wikipedia. Through these sources, new links and 3-D communities were identified. Experts and user-communities within the area of CAD and visualization were also consulted *(Attachment 1).*

As a start, identified design-tools were explored, pursued or excluded based on the feedback and recommendations received. This also included customer reviews available online. The computerized tools were further evaluated against some very fundamental requirements. If these were not met, no matter its functionalities the design tool was deemed unsuitable for its purpose. This further meant that some potentially outstanding design-tools were ruled out, without the chance to test its performance.

3.2 Evaluation Methods

3.2.1 Concept Screening and Scoring Matrix

Once the exploration of design-tools was considered satisfactory, the actual testing period began. At this point, tools were evaluated against some predefined criteria based on theories about usability and responses received from respondents. These were evaluated in the structure of *concept screening* *matrix*. The results of the concept-screening matrix provided a comparative score. These helped determine which tool(s) was most likely to reflect the level of usability required for the inexperienced users, and be the most suitable for the OHS practitioners. However, the criteria were given equal value despite the probability that they wouldn't be valued equally in real life. This was solved by letting the most representative OHS users weight the importance of each of the criteria to reflect its value to them, so-called concept *scoring* matrix. During the same session, *usability testing* was performed on the one tool that reflected the highest score in the concept-screening matrix. However, for reasons explained later, all of the evaluated tools were to be affected by the concept-scoring matrix in which revealed further results.

3.2.2 Usability Testing and HTA

"Every good project starts with a task analysis and ends with a user trial". "All too often this goes unheeded, and the resulting design solution is inadequate, either facilitating only some aspects of the use of the product or satisfying only some of the potential users" (Pheasant and Haslegrave, 2006, p.13).

Usability testing is an experimental method where representative users are set to interact with the system or product being evaluated, by completing a number of preselected, relevant and realistic tasks (Osvalder et al., 2010). A purpose of usability testing is to include the potential users in the usability evaluation, by collecting valuable feedback concerning their experience with the system interface (Osvalder et al., 2010). Osvalder et al. (2010) emphasize that any issues users are faced with during usability-testing very highly reflect the issues that they will experience using the tool in real life.

In the following study, the tasks chosen was based on a HTA-analysis created prior to the usability testing. The analysis covered steps and tasks that were considered essential for OHS practitioners when applying a design-tool during workplace design. It was based on information conveyed by the initial project leaders and KTH researchers, from the two informative participants, as well as applicable topics described in the literature review. The HTA was considered a necessity in order to define the overall goals of the design-tool, and the number of steps required to reach those goals. The analysis reflected both a realistic and desirable process, i.e. it was built on an already established process, with additional suggestions of future tasks and use.

3.2.3 User Selection

A common guideline is that 75-80% of all usability problems incur when 5 to 6 users are included in the testing. Increasing the number of users does not necessary provide greater results (Osvalder et al., 2010). The respondents should ideally be representative in terms of whom the system is intended for, i.e. the end-users (Pheasant & Haslegrave, 2006). Pheasant & Haslegrave (2006) further argues that a useful strategy is to test the system on the users who are most prone to experience difficulty using it, for the reason that a product acceptable to these users are likely also to be acceptable for the majority of other users including the higher skilled. This reasoning was followed when recruiting respondents for the usability testing. This meant determining the most representative users, while examining the user-groups with the least experience with computerized design software.

Representative Users

According to SOU (2011), most OHS practices are highly multi-professional. Yet, despite their joint focus on occupational health and safety, the different professions seemingly perform different tasks complying with their specializations. The most representative OHS practitioners concerned with workplace design were, according to SOU (2011) Ergonomists and Safety-engineers. The ongoing study of Holm (2015) further reveal that workplace design is quite a common area for Ergonomists and Safety engineers to be involved.

Respondents' Response: Safety-engineers and Ergonomists

The information conveyed during the two qualitative interviews determined that the two most representative users for workplace design were Safety-engineers and Ergonomists. Ergonomist was viewed to be the profession with the least experience with computerized design-tools and thus the most representative in terms of the method described in Pheasant and Haslegrave (2006). The respondents further emphasized that the most ideal is that the two professions work together as a team. The emphasis put on teamwork was another factor influencing the selection method.

The above information resulted in the following selection for the Usability-testing:

- *Two individual test-interviews with Ergonomists*
- *Two pair test-interviews consisting of one Safety-engineer and one Ergonomist*
- *Four test-interviews altogether, six individuals.*

The individual test-interviews with Ergonomists were believed to reflect the degree to which the proposed tool reached a level of Usability required for the inexperienced users of CAD, while further evaluating whether it was applicable to individual OHS practitioners involved with workplace design. The pair-interviews with Ergonomist and Safety-engineer together were chosen to resemble a real-life scenario where the two professions were collaborating during workplace design projects. Another purpose of this method was to illuminate the users' experience and interaction with the tool when both professionals were collaborating as a team, contra when they were on their own. This was also considered valuable for revealing a potentially "best method".

In order to truly reflect a representative sample of the intended population, both gender and age of the primary users was considered. Statistiska Centralbyrån (2015) and Företagshälsor (2015) were both consulted due to the lack of complete statistics for OHS practices in Sweden (Statistiska Centralbyrån, 2015; Företagshälsor, 2015). Some of the reasons for the lack of precise statistics were the following:

- Occupational Health Service is not a protected title and thus may include even those who aren't practicing what the industry is thought to be practicing (Företagshälsor, 2015).
- Not every OHS-company is registered with the OHS Association (Företagshälsor, 2015).
- Individual OHS practices may not be included in the National Statistics if it is part of a particular company (i.e. internal OHS practices) (Statistiska Centralbyrån, 2015).
- The existing statistics for Safety-engineers and Ergonomists are incorporated into industry- and professional designation-codes, and inseparable from other industries and professional titles under the same codes (Statistiska Centralbyrån, 2015).
- Due to the inseparable professional codes mentioned above, it was furthermore not possible to separate Safety-engineers from Ergonomists.

Hence, despite not being fully thorough, the following statistics from Statistiska Centralbyrån (2015) provided a rough idea about the age- and gender distribution, when merging the two codes relevant for Safety-engineers and Ergonomists within OHS practices. This was calculated as the following:

The OHS practitioners are consisting of 65% women and 35% men.

Gender	16-34 years old	35-49 years old	50-64 years old
Female	6%	46%	45%
Male	4%	26%	70%

Further Demographics

A representative from Företagshälsor (2015) explains that to their knowledge there is far more women than men who are Ergonomists in the industry, contra for Safety-engineers where they are predominantly men. The age-level of OHS practitioners was generally considered high, particularly for Occupational Doctors and Safety-engineers. One of the interview respondents further elaborated about a drastic age curve for Safety-engineers, expressing that Safety-engineers within OHS practices were either close to retirement age or newly graduates with limited work experience. The middle segment of ages 35-50 was considered almost non-existing, with the exception of a few around age 45.

Final Selection

With the statistics being so interpretable, a higher priority was set to recruit participants that were representative in terms of their title, work tasks and collaborations with each other. Participants with the suitable professional titles were to be actively working as an OHS practitioner as well as currently be, or have been involved with workplace design. The pair of Ergonomist and Safety-engineer was to currently be working together within the same OHS practice, to reassure that they were not two strangers collaborating for the first time during the usability-testing session.

The final selection was:

- 1 female Ergonomist 50-64 years old.
- 1 male Ergonomist 35-49 years old.
- *Pair (1):* One female Ergonomist (50-64 years old) and one male Safety-engineer (50-64 years old).
- *Pair (2):* One female Ergonomist (35-49 years old) and one male Safety-engineer (35-49).

All of the OHS practitioners were working within internal OHS practices.

3.2.4 Practical Arrangements during Usability Testing

Usability tests were performed in private rooms from the authors' laptop computer. Three out of the four usability-tests were performed at the OHS practitioners' own workplace, whereas one was conducted at a University location. The usability testing consisted of several parts. Firstly, respondents were introduced to the process of workplace-design, including a rough overview of the HTA-analysis (section 4.2.4) outlining where the inclusion of a CAD-tool was regarded the most relevant. Following an introduction of the proposed design tool, a predefined degree-of-intensity scale was used for ratings prior to, but also subsequent to the testing sessions. The criteria were defined as claims that were measurable through the scale, consisting of ranked multiple-choice answers (refer to section 5.2.1 for a more precise illustration).

During the actual testing, respondents were asked to test different functions based on some of the most relevant steps in the HTA-analysis (see section 5.2.2). That is, the steps necessary for the desired outcome of the proposed design-tool. The sequence was organized so that the first and the last tasks were of easier nature. This, according to Osvalder et al. (2010), helps the user feel more secure and confident with the testing experience. The testing time, including introduction tutorials, was set to 35 minutes, whilst the entire session including scorings and follow-up interview was prepared to last up to an hour. This follows the recommended session time in Osvalder et al. (2010). However, due to technical issues, most sessions lasted slightly longer.

Equipment

During usability testing, Osvalder et al. (2010) stresses the usefulness in recording respondents interacting with the interface. This include videotaping users and/or the interface, alternatively sound recordings particularly helpful for a "talk out loud" method where users are encouraged to express verbally what they are thinking.
For this particular study, video recordings were made of the screen in order to follow the actions performed within the interface, but the users were not videotaped for sensitivity reasons. This is supported by Jacobssen (2011), which argues that videotaping may cause the user to act differently. A sound-recorder was used to record verbally expressed information, but the user(s) was not encouraged to "talk out loud" because it may distract the novice user during the solving of new tasks (Osvalder et al., 2010). Respondents were

further informed about anonymity and that recordings were erased following the analysis.

3.3 Analysis

Once reaching the stage for analysis, usability-tests were analyzed based on both qualitative and quantitative information, as stated in Osvalder et al. (2010). The qualitative information was based on the conveyed information during the ratings and the follow-up interview. The information was systematized, reduced, categorized and further compared in able to identify patterns. The quantitative information was found in the numbered ratings, the performed actions in screen-recordings in combination with any other verbal information conveyed during the testing. Aspects that were observed were number of errors and kinds of errors, number of corrected actions, time taken to achieve tasks, hesitations, collaborations, etc. Ratings were further calculated using descriptive statistical measures, such as the average score and mode value.

Given the purpose of the study was to propose a match, both categorizations and comparisons were important steps of the analysis. A match indicated that comparisons needed to be made in this case between the user requirements, usability principles and tool characteristics. Comparisons between individual and pair-sessions were also conducted. The concept matrices were necessary methods for this. They were chosen over other usability evaluation tools such as CW (Cognitive Walkthrough) and PHEA (Predictive Human Error Analysis), due to their flexibility and adaptability to the evaluators' and users' own defined criteria and weightings of these, while further providing a comparative score (Ulrich and Eppinger, 2008).

4.0 Part Results and Analysis

4.1 Interaction Analysis; First Step

In this section the following is described:

- The purpose of the evaluation
- Which use to be evaluated; criteria chosen for evaluation
- The process of excluding and including tools to be further tested

Quotation Marks and Referencing

Direct quotes were used in this study. However, since most respondents were Swedish-speaking, all quotes were translated to English.

Respondents in this section were referenced to with the following identifications:

Respondent A and B = The *informative* respondents contributing during the first step (3.1.2).

4.1.1 Purpose of the Evaluation

A desired outcome of this study was to identify computerized design tools applicable to the particular user group. Hence, criteria for evaluation needed to both match principles of Usability for inexperienced users, in addition to the specific requirements and/or desires from OHS practitioners. Design-tools further needed to mirror the general functionality required performing tasks necessary to meet the overall goal of their use, e.g. the ability to copy the necessary details of a drawing-proposal into the software, including rendering the proposed environment. For a more thorough overview of the goal of their use, refer to section 4.2.4, HTA-analysis.

4.1.2 Criteria Chosen for Evaluation

During and following the identification of computerized design-tools, software were either excluded or included for further testing based on some basic yet crucial requirements. Some of these requirements were outlined in 4.1.1, such as the functionality needed to mirror the overall purpose of the tool:

- *Three-dimensional CAD-software*
- *Capable of building an office-layout*
- *Capable of visualization from different angles*

Other requirements were clarified by the respondents A and B, such as:

- *Be suitable for inexperienced CAD-users*

A general hypothesis in this study was that OHS practitioners were inexperienced with CAD-software. Respondents indicated that such a statement was true, although a great variety existed. For a more thorough description of the practitioners experience level, refer to section 4.2.3.

- *Compatible with Windows and Mac*

Computers' operative system was found a crucial factor to consider. Both respondents indicated that Windows were the most dominant operative system used within well-established OHS practices. Apple/Mac was now becoming more common within the newly established practices.

- *Cost requirement: Max 10.000* SEK

Costs were perceived as crucial determinant for OHS practices to approve of a design-software. Respondents emphasized a strong cost pressure within OHS practices, explaining that it is an industry quite unprofitable and that any costs invested in a design-tool would need to be strictly justified. A maximum price-range of 10.000 SEK was interpreted as an acceptable investment.

- *Language requirement: English*

Although Swedish language may be preferable by the Swedish population, it was generally believed to be a desire rather than a requirement.

Table 4.1) Summary of the basic requirements for tools

Summary of the basic requirements for tools, prior to evaluation
• Three-dimensional CAD-software • Capable of building an office-layout • Capable of visualization from different angles • Suitable for inexperienced CAD-users • Compatible with Windows and Mac • Cost requirements: Max 10.000 SEK • Language requirement: English

4.1.3 Identified Computerized Design-tools

Following figure (4.1) is the result from the search of computerized design-tools:

- ArchiCAD
- AutoCAD Architecture
- Imperial UnitsOffice Layout
- Factory Design Suite
- 3d Studio Max
- Autodesk Homestyler
- TinkerCAD
- ✓ **SketchUp**
- Easyplanner3d
- 3DVIA Shape
- Sweet Home 3D
- E-draw
- Concept Draw Pro
- ✓ **RoomSketcher**
- MyDeco 3D Roomplanner
- Roomstyler
- ExhibitCore Floor Planner
- Solidworks
- ErgoCAD ARCHlineXP
- Microstation
- CADkey
- Smartdraw
- QCAD
- Revit
- QuickCAD
- ✓ **Floorplanner**

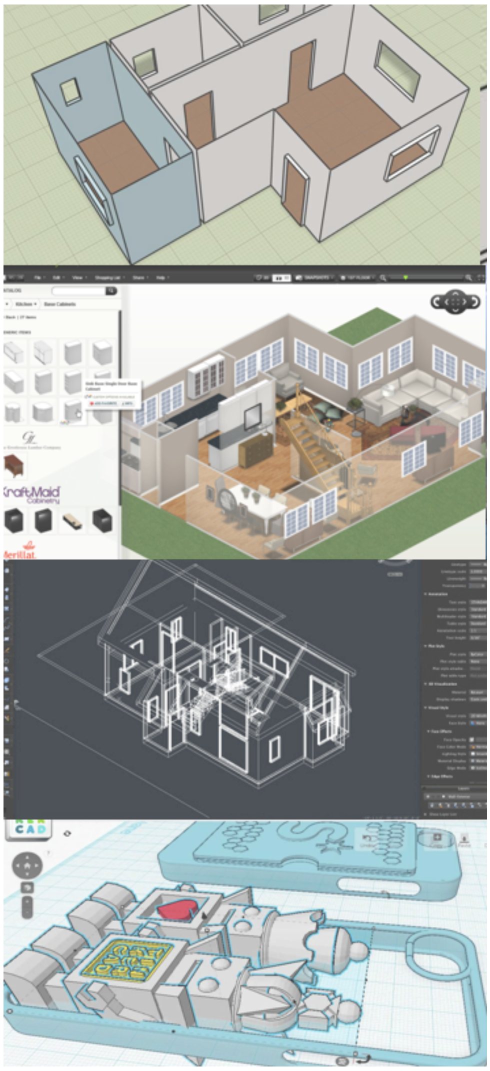


Figure 4.1) List of identified CAD-tools. Illustrations from AutoCAD, Homestyler, 3DVIA shape, Tinkercad.

With the help from experts and user-communities, the above-mentioned tools were either excluded or preceded for further testing. Most tools were perceived unable to fulfill the basic requirements, although with some exceptions. The tools with a checkmark next to it were further tested in the style of *Concept Screening Matrix* (see section 4.2.6), based on the more thorough criteria defined below.

Arguments for Exclusion:

The reasons for exclusions were comparative with the basic tool-requirements. A few of the tools simply weren't three-dimensional or were incapable of visualizing three-dimensional environments from different angles. Others weren't capable of resembling a detailed office layout i.e. offered too little flexibility in the interior design, or were unsuitable for office-layouts. Many were perceived too advanced for inexperienced CAD-users, while reflecting functionalities likely not necessary such as detailed construction or animated capabilities. A couple of the tools were too expensive, exceeding the limits of the recommended costs. Another tool was not available in English or Swedish. A potentially great design-software very recently resigned. Other software experienced technical issues that provoked a less serious impression.

4.1.4 Criteria Chosen for Concept Screening and Scoring Matrix

The following list displays criteria chosen for evaluation, with explanation of their relevance to this study.

Recommendations = *To which degree concepts have received positive reviews and feedback.*

Due to time limitations and the authors' lack of experience with CAD emerged a need to consult more experienced professionals and user-communities already familiar with the software. As mentioned in section 3.1.3, this included various different methods, all of which would be relevant for this criterion.

Successful Task-performances = *To which degree concepts have the ability to achieve the intended tasks.*

This criterion is a distinguished part of the usability definition and phrased to resemble the term *effectiveness* (Schneiderman and Plaisant, 2010). It was believed to be crucial for fulfilling the goals of the design-tools' use.

Quality of Outcome = *To which degree the end-result is reaching the expected outcome.*

This phrase was likewise set to resemble the term *effectiveness* as part of the usability definition. It was believed to play an essential role in facilitating visualization and communication of blueprints of future offices.

Learnability = *The required effort and training to reach a competent level of performance.*

"Learnability" is a term derived from usability' *efficiency* and was found particularly valuable for inexperienced users (Schneiderman and Plaisant, 2010). This was further emphasized by respondents A and B of this study. *"A two-day course should not be necessary, because the time is not available"* (Respondent B). Learnable interfaces could be about visual clues given in the interface, understandable terminology as well as clear conceptual models. Furthermore, online user manuals should not be constantly required to perform tasks (Schneiderman and Plaisant, 2010).

Memorability = *To which degree methods to achieve tasks are easily memorable.*

Another term relevant for usability and ease of learning is a concepts' memorability.

Speed of Performance = *The speed to which desirable tasks are achieved, once familiar with the interface.*

As part of the usability-definition, the term concerns a concepts' efficiency, i.e. time required for performing tasks (Schneiderman and Plaisant, 2010).

Error Prevention = *To which degree the software help the user recognize, diagnose and recover from errors made, within a timely and effortless manner.*

Yet another crucial aspect of efficiency was found to be the error-rate. Receiving the diagnostic feedback is to an inexperienced user essential to recover from error within a timely manner (Schneiderman and Plaisant, 2010).

Satisfaction = *To which degree the user experiences a usefulness and satisfaction with functions and features of the software, including the support in performing the desirable tasks.*

Satisfaction is part of the usability definition and interpreted as an essential measure for evaluating Usability.

User-manuals = *To which degree online user-manuals in the software are easily searchable while not interfering with the tasks.*

While user-manuals may be considered essential for inexperienced users, if inaccessible or interfering with other tasks in the interface they risk being counter-effective (Schneiderman and Plaisant, 2010; Jordan, 2002).

Simplicity = *A few number of actions are required to perform tasks successfully. Vocabulary are few, familiar and consistent. The software is intuitive and guessable.*

Simplicity is a term very useful for building the trust and confidence in inexperienced users (Schneiderman and Plaisant, 2010). Both respondents in this study expressed a need for the tool to be simple, user-friendly and intuitive.

Feedback = *To which degree informative feedback is given on performance.*

While poor feedback diminishes learning, informative feedback can help the novice user learn and feel more secure about their performance (Wickens et al., 2004).

Cost = *In comparison to the other concepts within the matrix and the maximum cost requirement, each concepts' cost is given a measure based on how "expensive" or "inexpensive" they are.*

As described in section 4.1.2, costs were a determining factor expressed by the respondents. The higher the costs, the better argument were needed.

Required Disk Space = *Software requiring as little disk space as possible.*

Both respondents indicated a need for the software to require as little disk space as possible. This was particularly due to its' need to be moveable (i.e. be storable in a laptop) in cases that the software was to be applied at a company's location.

Moveable = *Is the software moveable to an external disc?*

This measure is most likely a yes or a no, and relates to whether or not the software is moveable to an external hard disk drive. The respondents, for similar reason as above, appreciated such a capability.

Language = *The degree of satisfaction with the language(s) within the software.*

Both familiar and consistently used vocabulary may play a role for the novice user's experience and understanding of the interface. For a Swedish population, this may be as simple as whether or not the software is available in both Swedish and English. If the latter, design-tools' dimensional units: i.e. whether dimensions are shown following the International System for Units (SI) or the United States Customary System Units (USCS) are of relevance.

4.2 A Description of the Human-Technology System

The following section describes the *human-technology system* through a thorough analysis of each of the components:

- The users
- ➢ The user's environment
- ➢ The user's tasks
- The interface of the concept chosen for user evaluation

Similarly to the previous section, several of the steps highly reflected the information conveyed during the qualitative interviews performed with the two first respondents of this study. Other contributors, such as CAD-experts, were also referred to in this step.

4.2.1 User Profile

4.2.2 User Roles and Their Level of Interaction with a Design-tool

It was previously determined the potential primary users of the design-software as well as their gender, age, and previous experience with CAD-tools. But a design-tool can affect more than just the primary users. This is best illustrated through a table defining the primary, secondary, side- and co-users:

Table 4.2) Potential user roles and their level of interaction with a CAD-tool

User roles		*Level of interaction*
Primary users	- Safety-engineers. - Ergonomists.	Manipulates and uses the tool directly for its primary functions and purpose.
Secondary users	- Safety-engineers and Ergonomists. - The end-users: employees and management - Project-group including Health and Safety Committee. - Architects.	Is involved in the tools' secondary functions, i.e. the tool is applied as a communicative medium.
Side-users	- Architects. - Others within the OHS-team such as Occupational Nurses and Behaviorists.	Is positively or negatively affected by the tool, without being the primary or secondary user.
Co-users	- Architects including Lighting, Electricity and Ventilation-Installers and Consultants. - Others within the OHS-team such as Occupational nurses and Behaviorists.	Collaborates with a primary or secondary user without directly interacting with the tool.

Architects

The above interpretation was categorized based on information conveyed by the two respondents A and B. The interpretation was challenging, particularly due to the uncertainty of where in the process an Architect is and ideally should be involved. Interactions between Architects and OHS consultants were in this process understood as mainly indirect. OHS consultants were given access to drawing-proposals of the proposed work building while given a chance to provide feedback against the proposals mostly in the style of written information exchange. Respondent B expressed that a more direct dialogue most often happened between the OHS consultants and the customer; e.g. the property manager of the company undergoing the changes. In fewer cases, a more direct dialogue could happen between OHS-consultants and the Architect, alternatively as a group consisting of OHS-consultants, company management and the Architect.

Respondent B elaborated that the most ideal would be if Architects inserted their drawing-proposal directly into the software, presented it to the OHS and requested their feedback either through an in-person meeting or via a phone call to further examine the drawings together. However, such a process was believed to be too costly given that Architects and OHS-consultants together represented a cost likely to exceed the projects' budget.

For these reasons, Architects were found both representative as secondary, side, and co-users, all depending on their involvement and collaborations with OHS-consultants. At present, Architects were not known to be delivering their drawing-proposal as three-dimensional presentations to OHS-consultants. However, a CAD-expert consulted as part of this study expressed that three-dimensional presentation techniques have been and is commonly applied methods by Architects today. *"If OHS practitioners want to be involved in the scrutiny of 3-D models, they should contribute to that such demands are set of the projects and that Architects work out their proposals in 3-D models"* (CAD-expert, collaborating with Architects). Furthermore, an associate professor involved in visualization-techniques expressed that for the flow to be effective; Architects should deliver in 3-D.

These results further indicated that Architects, now set as collaborators, ideally could also be seen as one of the primary users.

Lighting, Electricity and Ventilation-installers and Consultants

Lighting and Ventilation-installers were set as co-users due to their possible collaborations with the OHS practitioners (primary users). There was some uncertainty as to whether these were also known to be secondary users, particularly if they were to be seen as part of the project-group. Respondent A expressed that Installers and Consultants that are working with processes such as lighting, electricity and ventilation are important stakeholders for communication and information exchanges. On another note, these professionals were not believed to directly benefit from a three-dimensional design-tool because of their need for a *"flat, two-dimensional view"* of where to insert their cords, for overview of their surfaces and dimensions, etc. A design-tool for them would be *"too fancy"* (Respondent B). Lighting consultants were further known to have their own programs for the spreading and rendering of lighting (Respondent B).

The End-users, Project-group, the Health and Safety Committee

The end-users (the company's management and employees affected by the changes) and project-group (including health and safety committee) were undoubtedly secondary users. Although they weren't seen to directly manipulate the tool, they could be seen as the visualization audience; *"You want to visualize for them to increase their understanding of how the planned workspace could look like in real life"* (Respondent A). Secondary users would be the ones affected by the changes, e.g. the management structure, the health and safety committee (Respondent B).

Others within the OHS-team; i.e. Occupational Nurses and Behaviorists

Respondents indicated that other OHS-practitioners; such as Occupational nurses and Behaviorists could have something to contribute to the planning of workplace-design. These were interpreted as side- and co-users as they occasionally collaborated with the primary users on design projects, but were not directly manipulating nor natural audiences of the visualization tool.

4.2.3 Characteristics of the Primary Users

From the previous step it was shown how primary users were the ones directly manipulating the design-tool and applying it for their main functions. These primary users were further analyzed based on their experience and knowledge with computerized-design tool, their environments and tasks to be performed as part of the application of a design-tool.

The Primary Users' Skill-levels

To reach a better understanding of the experience and knowledge of Safety-engineers and Ergonomists, respondents were consulted about their most probable skill-levels.

Safety-engineers were considered the most familiar with CAD-software, but they were not interpreted as skilled in any particular software. Some, in particular the younger generation Safety-engineers, were likely to be familiar with some of their functions based on previous knowledge and experience either from educational or practical use. Ergonomists were on the other hand, unlikely to hold this advantage with the exception of a few younger generation Ergonomists who potentially could draw on their experience from some of the more common computer-programs like PowerPoint, Word and Excel. These Ergonomists were likely to be able to *"open, read and look at it",* but less so working in it (Respondent B). The variations in behavior were believed to generate from age, education, level of acceptance, and need (Respondent A and B).

Environments

Understanding the environments a design-tool was to be used was perceived important in order to fully analyze the interactions occurring between the user and the tool. For this purpose, respondents were consulted about which environments a design-tool was likely to be applied.

Some of the alternatives were, as expressed by the respondents:

- In the Safety-engineers' computer.
- In a standard lounge computer placed at the department, accessible to all personnel within the department.
- In a stationary computer with a separate hard disk transferrable to a laptop, when requiring to be moved to different locations.
- At the customers (company) location; demonstrations performed at the company's own premises.
- In a meeting room, with room for a small group of people as part of the presentation.

4.2.4 Tasks

The tasks performed by Ergonomists and Safety-engineers during workplace design were understood to slightly overlap. This meant that Ergonomists and Safety-engineers could be working on similar tasks, while examining a problem from different angles. For these reasons, respondents emphasized a need for the two professions to collaborate as a team. For a more thorough description about the different areas Ergonomists and Safety-engineers examine, return to section 2.3.1.

Aspects to Consider during Drawing Examinations

From the perspective of occupational health and safety, here were some of the important aspects to consider during the scrutiny and examination of office blueprints, as conveyed by respondents A and B:

- The communication pattern; are people that need to communicate grouped together?
- Is the furniture suitable, e.g. desks and chairs?
- Floor surface; are premises large enough to fit the number of people it is intended for?
- The amount of toilets contra the number of people working there. Where are accessible toilets?
- Where are break-rooms and coffee-machines; can they be distracting to any of the employees sitting close to them?
- The placements of different departments, functions and activities, etc.

HTA Analysis

Below was the result of a hierarchical task analysis (HTA), covering the process from when a Safety-engineer and Ergonomist receive an architectural blueprint-proposal, to the moment that the three-dimensional built environment is visualized to the customer, alternatively project group.

In addition to reaching an overall greater understanding of the tasks performed, this step further clarified the evaluation of the principles:

- Successful task-performances = *To which degree concepts have the ability to achieve the intended tasks.*
- Quality of Outcome = *To which degree the end-result is reaching the expected outcome.*

0. In a three-dimensional CAD software, create a three-dimensional layout environment representing the architectural blueprint-proposal, in order to visualize the environment to the project-group inclusive of the end-users.

1) OHS' Safety-engineer and Ergonomist examine the architectural drawing proposal by themselves or together, i.e. blueprint, descriptions and specialty-drawings.

1.1) Safety-engineer and Ergonomist compare the details of the drawing to the intentions of the OH&S-input that they provided the Architect prior to the creation of the drawing-proposal.

1.2) Safety-engineer and Ergonomist examine the proposal for areas of importance. For examples of what the Safety-engineer and Ergonomist examine return to section 4.2.4.

2) The Safety-engineer and Ergonomist chooses and copies any relevant details of the drawing proposal into the design tool, all depending on the purpose of the environment e.g. nondetailed or detailed environment (section 2.4)

2.1) Based on the purpose of the environments created; the Safety-engineer and Ergonomist establish, translate and transfer the relevant details e.g. the correct positioning of floor surfaces, equipment & furniture, doors & windows, materials & colors, functions and activities, including exact dimensions and geometry.

2.2) The Safety-engineer and Ergonomist separately or together uses any available functions in the design-tool to draw, build and create a 3-D environment that represents how the drawing-proposal may look like in real life.

3) Safety-engineer and/or Ergonomist present the built 3D-environment to the project-group including end-users; e.g. representatives of the employees and management, health-and

3.1) The Safety-engineer and Ergonomist illustrate areas of importance (section 4.2.4), inviting attendants of the project-group to participate and contribute to the discussions about the proposed arrangements, advantages and disadvantages, potential issues and solutions, etc.

3.2) The Safety-engineer and/or Ergonomist present the 3-D environment from the relevant angles (e.g. top-view, eye-level view) while navigating with visualization tools such as pan, zoom and rotate, including any rendering techniques to illustrate the interior lighting and daylight.

1.3) The Safety-engineer and Ergonomist may further wish to consult the Architect, Lighting,-Electricity and Ventilation installers, potentially also Occupational nurses and Behaviorists, to acquire additional information about the drawing proposal and/or any missing details.	**2.3)** Depending on the available functions in the design-software, the Safety-engineer and Ergonomist may decide to include additional features to the 3-D environment such as human models and rendering-techniques.	**3.3)** The Safety-engineer and/or Ergonomist may further wish to manipulate the model during the presentation, e.g. by editing any proposed changes directly into the software.

A Summary of Relevant Tasks to be Performed within a Design-tool

Designing

- Designing floor surfaces including all relevant dimensions such as rooms and corridors' height, length and breadth, threshold, steps and stairs including the dimensions of cleared spaces.
- Adding the correct equipment and furniture, e.g. visual displays, chairs and desks, as well as doors, windows and glazing, including exact dimensions and geometry.
- Positioning and moving furniture correctly in space.
- Choosing materials for furniture, interior and flooring e.g. floor mats.
- Adding any necessary colors e.g. to create contrasts in the environment.
- Defining different functions, rooms, groups and activities e.g. to determine communication patterns and noise levels.

Visualization

- Choosing visualization views that match the purpose of the presentation, in particular top-view and close up eye-level view. Further navigating around the model.
- Rendering techniques to determine the lighting within the building, e.g. daylight and interior lighting.

Manipulation

- Editing any changes directly into the created model.

4.2.5 The Interface of the Concept Chosen for Usability Testing

Which computerized design tools for facility-layout exist on the market that attains a level of Usability required for the inexperienced users of computer aided design?

All three tools; RoomSketcher, SketchUp and Floorplanner were believed to reach the basic requirements described in section 4.1.2. However, the tool with the highest calculated score within the Matrix (4.2.6) was the only tool selected for the final usability testing. Therefore, a more thorough description of this tool can be found below.

<u>SketchUp</u>

SketchUp (figure 4.2), a modeling software owned by Trimble Navigation Ltd was released year 2000 (masterSketchup, 2011). SketchUp is used by numerous professionals within architecture, landscape planning, product-development and film (Trimble Navigation Limited, 2013). SketchUp has been well known for its suitability even to beginners, without any CAD-experience.

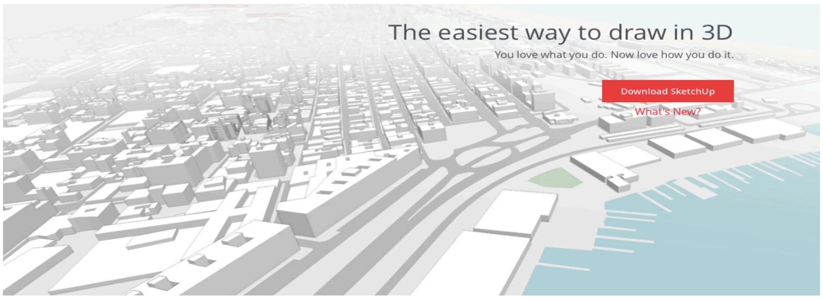


Figure 4.2) The front page of SketchUp (Trimble Navigation Limited, 2013).

Recommendations: SketchUp appeared to be highly recognized and reputable software well known by most professionals with some connections to the CAD-community. SketchUp was recommended as a CAD-software for inexperienced users by several of the contributors of this study, such as CAD-experts, Associate professors, and a user-community.

"In SketchUp, it is possible to start modeling straight away. You have a better sense of control in SketchUp compared to more advanced CAD-software... It is suitable for complete beginners to experts" (3-D Developer Engineer).
During the early stages of design, SketchUp was also known to be used by Architects (Architect, CAD-expert).

Successful Task-performances and Quality of Outcome:

<u>Designing</u>

☑ *Accurate dimensions of floor and room surfaces*

SketchUp had much functionality in place to support the user in drawing and connecting objects accurately in 3-D space. For instance, similarly to the other two design tools, blueprints could be uploaded into the model to facilitate the copying of details from 2-D to 3-D. Moreover, so-called *snapping* abilities used existing reference points to help the user connect to edges and surfaces in able to draw accurately. Different colored dots displayed nearby the mouse pointer represented vertical, horizontal and diagonal axis points to help the user recognize at which angle they were drawing. The tool could further help recognize midpoints and edge points, while providing the functionality to draw from existing geometry (figure 4.3). Since drawing directly in 3-D space, the user would receive direct feedback of the end-result of the model(s) built. This differed from the two other design tools that were editable in 2-D space only.

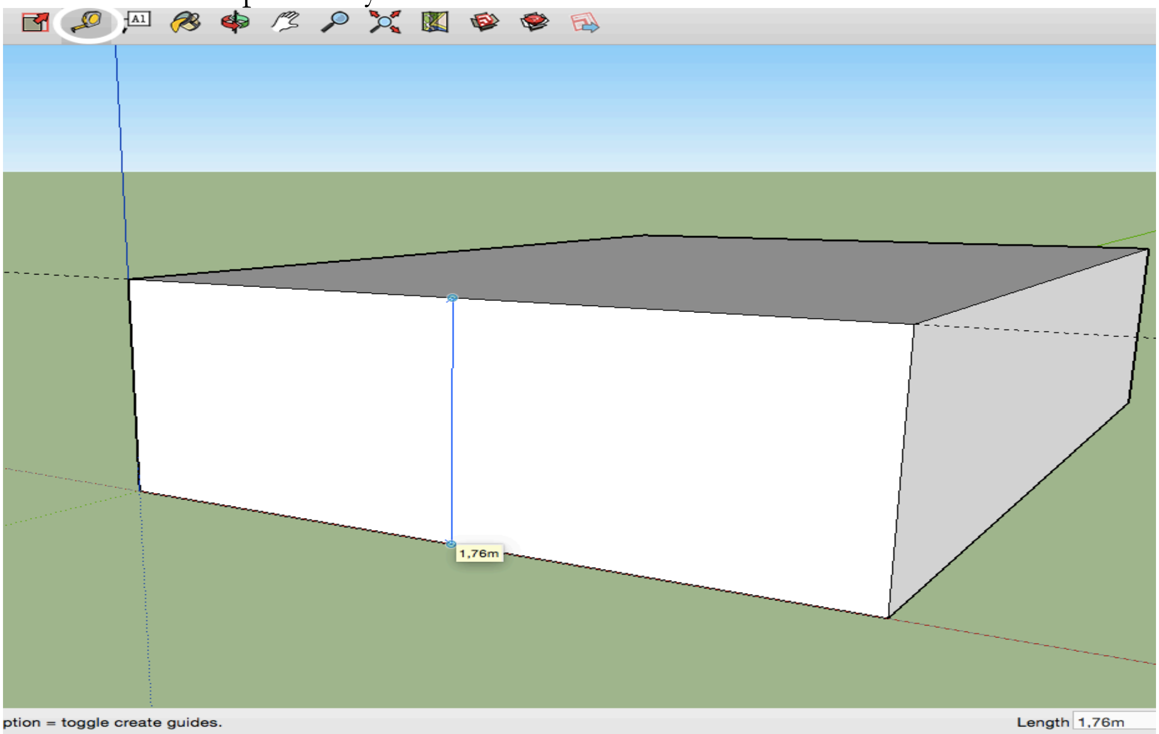


Figure 4.3) An example of how the software help recognize midpoints and measuring for accuracy via a tape-measuring tool.

☑ *Floor surface design*

When designing floors; floors could be separated and raised efficiently, even purposely be drawn at an uneven angle.

☑ *Correct equipment, furniture and other important elements including exact dimensions and geometry*

The software showed a significantly higher collection of furniture in comparison to the other design tools. Furniture was available through an online-library called 3-D warehouse. When searching for a "chair", the 3-D warehouse showed results of 27,964 different models. In addition, furniture could be organized into *groups of components* or *assemblies* (figure 4.4). This meant that each of the part models a whole furniture is made up of were adjustable to resemble specific geometries and characteristics. This unique feature was not found in the two other design tools. In addition to furniture, the 3-D warehouse further stored a variety of human models downloadable into the model. Both the quantity and quality of these models were observed higher in SketchUp.

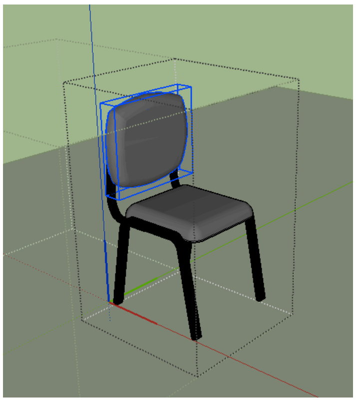


Figure 4.4) Example of a part model in SketchUp Pro

☑ *Correct positioning of furniture in space*

Furniture could be placed and moved anywhere in the model or rotated in any direction. Tape measuring abilities and other support in terms of reference points helped position furniture accurately in space, based on precise dimensions and distances.

☑ *Correct material for furniture, interior and flooring*

Several different materials existed within the model. It was further possible to upload own realistic images of materials. Materials could be applied to anything in the model.

☑ *Color inclusion*

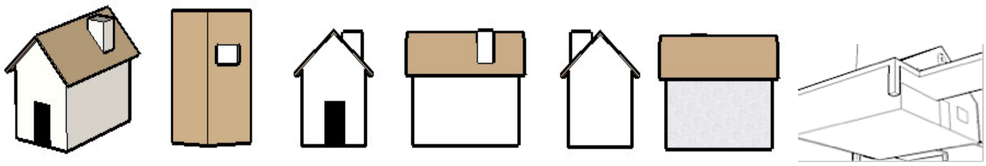
A paint bucket tool made it easy to find any color range desirable and include them anywhere in the model.

☑ *Definitions of functions, rooms, groups and activities*

Similarly to the two other design tools, text could be included anywhere in the model in the style of both two- and three-dimensional text.

Visualization

☑ *Visualization and navigation of relevant views:*
The actual drawing template could be displayed in any of the following views:



Isometric Top Front Right Back Left Bottom

(Trimble Navigation Limited, 2013).

The many available options of views made the designing adaptable to any purpose the user had in mind. All views were further possible as visualization features during or subsequently to designing the model, by applying the tools *rotate*, *pan* and *zoom*. Moreover, a so-called *walk-around* tool could bring the user up-close to the designed environment while moving around anywhere in the model, at a self-chosen eye-height level.

An additional visualization feature, *layout*, could isolate specific parts of a model to be visualized. The visualization features within the software showed potential to provide higher quality visuals than the two other design-software.

☑ *Rendering techniques for lighting dispersion*
Rendering techniques for daylight was accessible from within the software. By entering a specific time of the day a realistic view could be displayed of the dispersion of daylight inside the model. An additional feature for rendering interior lighting was downloadable from an outside source from the so-called *Extension Warehouse*. This last function was not possible in the other two design tools.

☑ *Manipulating a finished model*
Direct manipulations could be performed directly into the model. For the sake of visualization, manipulations could be performed efficiently, given that the designing was done in 3-D space.

Learnabiliy: The tools and symbols in SketchUp were representative to real-life metaphors. Very occasionally, informative feedback was given which facilitated learning the software. A so-called Instructor-tool could be applied throughout the designing phase, which could be described as an interactive *guide* particularly useful for beginners (figure 4.5). Nevertheless, the frequent need for an Instruction tool during the learning phase could reflect a longer learning curve or simply be seen as a necessary prerequisite for a beginner. Other learning support tools such as *self-guided tutorials*, was found very useful and effective for learning the software.

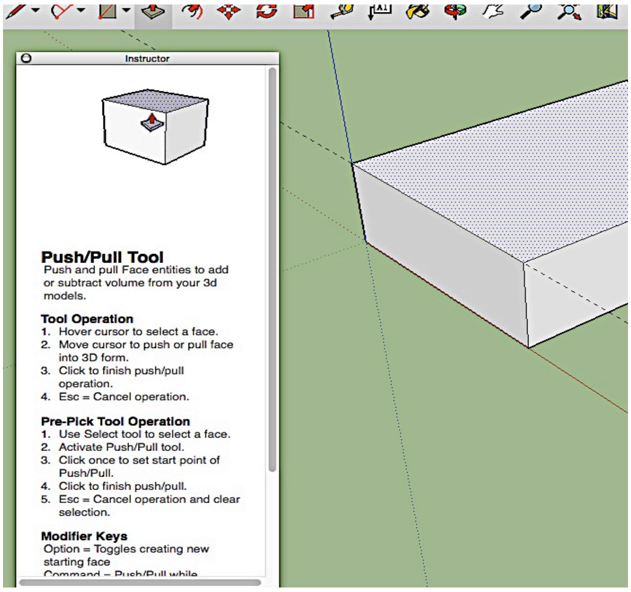


Figure 4.5) To the left: example of an Instructor tool.

Memorability: Some of the functions in the software were found easily memorable, while some other functions were not. While many of the tools were recognizable icons, some actions did not follow the conceptual rules commonly found in other computer programs. This lack of resemblance to other software' functionality made it necessary to learn a new set of rules, which became more time consuming to memorize.

Speed of performance: Overall, very few issues were experienced within the drawing template. However, with functions that required online access the evaluator occasionally faced technical issues. Since SketchUp' technical support was not aware of most of these difficulties, a slow speed of performance could very likely be caused by poor Internet connection.

Error prevention: Error recovery was possible with *Undo*, *Redo* and *erase* functions. The Instructor tool provided information about available actions, but was not found to inform the user of faulted actions. Nevertheless, since visual feedback of performed actions was a natural characteristic of the 3-D interface, this could help the user identify when errors have been made and thus be able to immediately correct these.

Satisfaction: The evaluator experienced a high level of satisfaction when interacting with the interface and functionality of the software. Most difficulties and dissatisfaction was experienced during the very early phases of learning the software.

Searchability & interference of user manuals: User-manuals and guides were easily searchable and accessible from within the design template. However the *Instructor tool* could, in rare cases, interfere with some tasks within the design-software.

Simplicity: SketchUp was recommended for its intuitive and simple design. The constant feedback and snapping functions within the software made some of the designing phases both guessable and intuitive. However, in software with so many functionalities, additional learning would be required. In addition, not all actions were found logical thus requiring additional training. The other two design tools were most often observed simpler, more intuitive and guessable.

Feedback: The software was perceived to provide exceptional feedback prior to, during and subsequent to task performances, more so than the other design tools.

Cost: At the time of evaluation, SketchUp provided two options:

- SketchUp Make = Free version.
- SketchUp Pro = 579 USD per license.

A Pro-version was considered essential due to the licensing requirement for commercial purposes. Other significant features within the Pro version were the options of importing and exporting files such as dwg. and jpeg., and applying the full set of visualization features available within the software.

Required disk space

Windows/Mac:

- Recommended: 500 MB of available hard disk space.
- Minimum requirement: 300 MB of available hard-disk space.

Moveable: SketchUp Pro could be authorized on up to two machines in addition to being moveable to an external drive.

Language: At the time of testing, SketchUp was available in *English*, French, Italian, German, Spanish, Japanese, Korean, Brazilian Portuguese, Traditional Chinese, and Simplified Chinese. Units of measurements were optional following either the International System for Units (SI) or the United States Customary System Units (USCS).

4.2.6 Concept Screening Matrix

The evaluation of the design tools was organized into a Concept Screening.

SketchUp was made the comparative *reference*, given its capabilities to achieve most if not all of the tasks intended, while still being recognizable as an easy-to-use software.

	Concepts		
Selection Criteria	**A** *Room-Sketcher*	**B** *(Reference) SketchUp*	**C** *Floorplanner*
Recommendations	-	0	-
Successful task-performances	-	0	-
Quality of Outcome	-	0	-
Learnabiliy	0	0	+
Memorability	+	0	+
Speed of performance	0	0	-
Error prevention	-	0	-
Satisfaction	-	0	-
Searchability & interference of user manuals	-	0	0
Simplicity	+	0	+
Feedback	-	0	-
Cost	-	0	-
Required disk space	+	0	+
Moveable	0	0	0
Language	+	0	+
Sum +'s	4	0	5
Sum 0's	3	15	2
Sum –'s	8	0	8
Net Score	-4	0	-3
Rank	3	**1**	2

5.0 Final Result

5.1 Further Analysis of the Human-Technology Interaction

In this section the following was evaluated:

To which degree was any of the identified design tools applicable to OHS practitioners?

Potential users of the design-software evaluated the one concept that was rated the highest in the Concept Screening Matrix: *SketchUp*. This was now performed in the manner of Concept *Scoring* Matrix. All of the measurable evaluation criteria in the previous step were reapplied. However, this excluded the criterion for *cost, moveable, disk space* and *recommendations,* which were considered irrelevant and immeasurable for the limited time of testing during the usability testing. While the Concept Screening Matrix mostly evaluated the tools most likely to attain a level of usability required for the inexperienced users of CAD, this step further evaluated the highest scored tool in terms of its suitability to the potential users. This was a three step process including:

- The potential users' weighting of each of the criterion, as part of the *Concept Scoring Matrix*.
- The potential users' evaluation and scoring of *SketchUp* towards the criteria in the *Concept Scoring Matrix*.
- Calculation of the Net Score by multiplying the average scores with the weighting of each criterion in the *Concept Scoring Matrix*.

Quotation Marks and Referencing

Respondents in this section were referenced to with the following identifications:

E = Ergonomist during the usability testing.
SE = Safety-engineer during the usability testing.
-pair = Connected with a hyphen next to the E or SE, it classified that the Ergonomist and/or Safety-engineer was part of a pair session during the usability testing.
-ind = Connected with a hyphen next to the E, it classified that the Ergonomist was part of an individual session.
(E- and SE-pair) = A direct quote by an Ergonomist as part of a pair testing, but where the Safety-engineer was filling in the sentence with further details and/or clearly agreeing to the quote by the Ergonomist.

(SE- and E-pair) = A direct quote by the Safety-engineer as part of a pair testing, but where the Ergonomist was filling in the sentence with further details and/or clearly agreeing to the quote by the Safety-engineer.
Ergonomists were further referred to as respondents 1,2,3,4.
Safety-engineers were referred to as respondents 1 and 2.

5.2 Usability Testing

5.2.1 Weighting of Criteria

The six respondents (four Ergonomists and two Safety-engineers) involved in the usability testing were asked to weight each criterion based on its importance if applying a design-tool for the purpose outlined in the HTA-analysis, shown earlier (table 5.1). The purpose of the weightings was to represent the importance of each of the criterion related to *any* design-tool. Respondents were asked to weight each criterion both *prior to* and *subsequent* to testing the design-tool *SketchUp*. This strategy was chosen to make respondents familiar with the criteria prior to testing, while providing them a chance to change their weighting after interacting with a design-tool. This was considered useful in cases that they had not encountered similar design-tools previously.

Each criterion were weighted based on a rating scale of 1-5:

5= Strongly agree
4= Slightly agree
3= Neither agree or disagree
2= Slightly disagree
1= Strongly disagree

Criterions were further rephrased into *statements* to be applicable to the rating scale.

Table 5.1) Results from the weighting of criteria

Criterion	Weightings of criterion	Arguments
Successful task-performances: The design-tool shows ability to achieve the intended tasks.	5 *(E ind)* 5 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 3 *(E pair)* 3 *(SE pair)* Average: 4,33	Several of the respondents expressed that the software' ability to solve the tasks intended was absolutely crucial and a prerequisite for their desire to use the software. A respondent indicated that it could make a difference for their collaboration with Architects; that it was important to achieve a

		certain standard. Moreover it was believed to help the end-users of the future premises achieve a higher understanding of what the OHS practitioners were trying to convey.
Quality of Outcome: The end-result reaches the expected outcome.	5 *(E ind)* 5 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 3 *(E pair)* 3 *(SE pair)* Average: 4,33	Similarly to the above, respondents expressed a great desire for the design-tool to be capable of reaching the expected outcome. *"I don't think I would keep using it otherwise"* (E-ind 3). *"It's the whole point of the software"*, says another respondent. Quality of outcome was also considered important when collaborating with Architects.
Learnability: The design-tool is requiring little effort and training to reach a competent level of performance, e.g. visual clues and terminology make the interface understandable, comprehensible and learnable.	4 *(E ind)* 5 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 5 *(E pair)* 5 *(SE pair)* Average: 4,83	Most respondents expressed that learnability was very important for a design-software. Respondents indicated they did not have the patience to spend a lot of time understanding the software. The software should be user-friendly, quick to learn. *"I don't have particularly high expectations"*, says one respondent. *"Programs usually take a longer time to learn than originally thought"* (E-ind 4).
Memorability: The methods to achieve tasks are easily memorable.	5 *(E ind)* 2 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 4 *(E pair)* 4 *(SE pair)* Average: 4,17	Respondents indicated that memorability would not be relevant or required if the software was simple to use. *"The design tool should be so intuitive that memorizing it is not essential"* (E-ind 3). Memorability was by some still found helpful, particularly when returning to a software.
Speed or Performance: Desirable tasks are achievable at a high speed.	4 *(E ind)* 4 *(E ind)* 4 *(E pair)* 4 *(SE pair)* 4 *(E pair)* 4 *(SE pair)* Average: 4	While speed of performance was perceived important, many of the respondents were unsure what to expect from a computer-program. The risk of technical aspects such as network connection issues made it hard to expect and predict speed of performance in any software.

Error prevention: The software help the user recognize, diagnose and recover from errors made, within a timely and effortless manner.	5 *(E ind)* 5 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 5 *(E pair)* 5 *(SE pair)* Average: 5	Error prevention was highly appreciated by the respondents. *"When given the diagnostic feedback, one becomes more efficient and effective, with the ability to recover from mistakes easily, and to not repeat mistakes"* (SE-pair 2).
Satisfaction: You experience satisfaction with functions and features of the software, including the support in performing the desirable tasks.	5 *(E ind)* 4 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 4 *(E pair)* 4 *(SE pair)* Average: 4,5	Although highly subjective, respondents indicated that such a criterion could be important. *"If the other criterion is achieved, the level of satisfaction is likely achieved, too"* (E-ind 3).
User-manuals: Online user-manuals within the software are easily searchable while not interfering with the tasks.	5 *(E ind)* 4 *(E ind)* 3 *(E pair)* 3 *(SE pair)* 5 *(E pair)* 5 *(SE pair)* Average: 4,17	Although many of the respondents appreciated easily searchable and non-interfering user-manuals, some also expressed that a design-tool should be intuitive enough not to require their use.
Simplicity: The design-tool is intuitive and guessable, e.g. only a few number of actions are required to perform tasks successfully. Vocabularies are few, familiar and consistent.	5 *(E ind)* 5 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 5 *(E pair)* 5 *(SE pair)* Average: 5	All respondents indicated that such a criterion was extremely important. *"I don't have the energy or patience to use a tedious software"* (E-pair 1).
Feedback: Informative feedback is given on performance.	5 *(E ind)* 4 *(E ind)* 4 *(E pair)* 4 *(SE pair)* 3 *(E pair)*	*"It's good but not essential"*, says one respondent. *"I like that, but it needs to be relevant feedback"*, as opposed to constant feedback that could be a distraction and an interference. Feedback was by one

	3 *(SE pair)* Average: 3,83	respondent perceived crucial in able to move on to the next task. *"Feedback should be provided immediately, before it is too late and tasks need to be redone"* (E-ind 4).
Language: You are satisfied with the use of language in the design-tool.	5 *(E ind)* 4 *(E ind)* 5 *(E pair)* 5 *(SE pair)* 5 *(E pair)* 5 *(SE pair)* Average: 4,83	Nearly all of the respondents expressed that their satisfaction with the language of the software was a highly significant criterion. *"I am not sure how familiar I am with English"*, says one respondent. *"It is important for the language to be comprehensible"* (SE-pair 2). Nevertheless, language was not a deal-breaker for all. *"Images and symbols can be really good too"* (E-ind 3).

5.2.2 Results from the Usability Sessions

With the previous weighting of criteria, respondents were now familiar with which areas to focus when testing and evaluating the applicable design-tool. Four identical usability-testing sessions were performed with *SketchUp* software with the six participants. This meant that the sessions with the individual Ergonomists were no different from the sessions with the pairs of Ergonomist and Safety-engineer, although the organization during the testing differed.

The respondents were introduced to identical tasks with the same time limits and conditions during the testing sessions. The pair of Ergonomist and Safety-engineer was instructed to collaborate as a team to solve the tasks presented. Another strategy was to allow the pair to organize themselves as they wished to observe any potential patterns during the two professions' collaborations. All respondents were encouraged to try solving the tasks on their own initiative, and if needed, to return to any of the help-sections within the software.

The usability testing included the following tasks in the following order:

- **Task 1) Introduction via video tutorials** (13 minutes)

Respondents were introduced and instructed in the tasks relevant to the usability testing. All respondents watched identical tutorial sessions. However, during one of the pair sessions, WIFI disconnected and disrupted the ability to watch the third tutorial. Video tutorial 3 mainly informed the user of how to move, rotate and place furniture in space; this was the same function that the same respondents were unable to test later.

Other technical issues caused the screen to freeze each time the video bar was enlarged. This resulted in that 5 out of 6 of the respondents were forced to view the tutorials in a smaller screen measured to 12x7cm. This caused an issue for at least one of the respondents that openly expressed that she felt unable to see and learn the toolbar properly because of it.

- **Task 2) Navigation and familiarization with user-manuals and help sections** (3 minutes)

Respondents were encouraged to read and familiarize themselves with user-manuals and help sections that could be helpful during task performances.

Respondents navigated within the user-manuals without any apparent issues.

- **Task 3) Designing a model with a step-to-step Instructor guide** (6,5 minutes)

Respondents were asked to attempt building a model with the continuous guidance from an "Instructor" within the software (figure 5.1).

The respondents were handling the tasks quite well, with the exception of some hesitation particularly at the beginning. No distinct difference was found between the individual and pair-sessions.

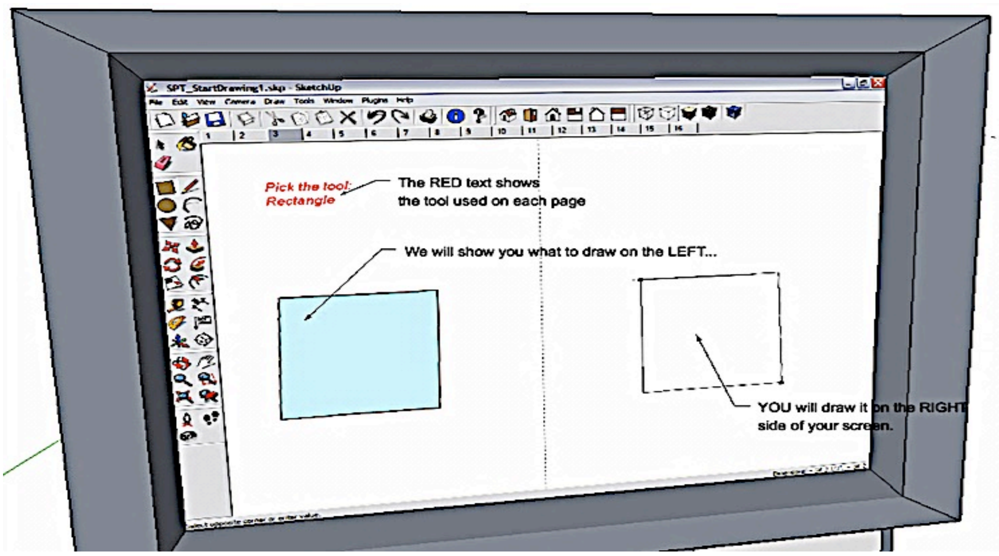


Figure 5.1) Respondents were instructed via a self-paced tutorial available within the software.

- **Task 4) Editing and manipulating an existing model of an office environment** (5 minutes)

Respondents were provided with an empty space within an office model and asked to test any of the functions in the software e.g. adding or moving around furniture (figure 5.2), applying materials, paint, measuring tools, etc. Respondents were encouraged to have open the *Instructor tool* for guidance throughout the tasks.

Most respondents expressed some frustrations and difficulties during this task. Although respondents were given an option to edit the office-space as they wanted, most respondents chose to include, position and move furniture within the model. Several of the respondents struggled with this feature. Most respondents were able to choose and upload relevant furniture efficiently, but experienced difficulties once attempting to resize, move, position or rotate the chosen furniture. Some of the respondents further tested on painting and measuring spaces. Fewer difficulties were expressed during these tasks.

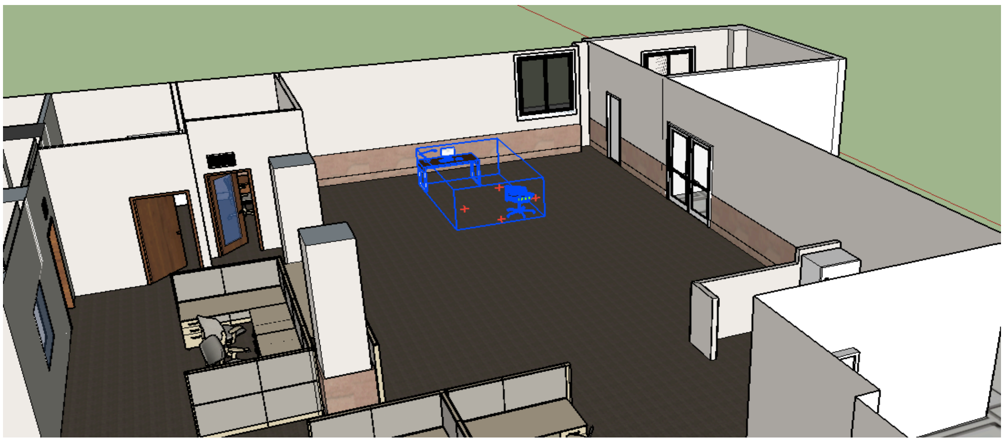


Figure 5.2) Example of a furniture group being added onto the workspace.

- **Task 5) Visualizing the office environment with the use of visualization features within the software** (5 minutes)

Respondents were encouraged to test all of the visualization features of zoom, pan and rotate and to test *walking* around the office model with the application of the *Walk Around* tool (figure 5.3).

Respondents were overall, quite enthusiastic about this feature. Respondents expressed that they felt in control of the visualization features and were able to navigate around the model quite easily without the experienced frustration. *"I think I could handle this, this feels easy"* (E-ind 4). Respondents further expressed fascination with the visualization features, e.g. being able to display relevant views and moving around in the model. Some respondents faced some issues with the *Walk Around* feature, due to accidently walking into walls. *"To go out to a company to present, and applying the feature of following a person walking around and then having to control so it doesn't walk into walls.. that doesn't feel so nice"* (E-ind 3).

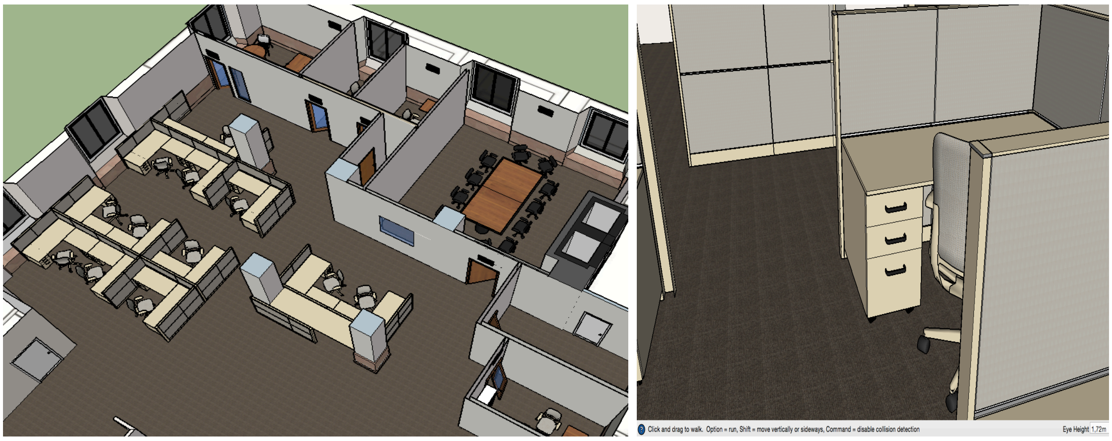


Figure 5.3) With the visualization tools respondents were able to view the model from many different angles, similarly to what they would be doing in a real life scenario.

5.2.3 Concept Scoring Matrix

The following was the results from the respondents' scorings of the design-tool *SketchUp*.

Successful Task-performances (*The tools' ability to achieve the intended tasks*):

Respondents expressed the most satisfaction with the software' successful task-performances (see figure 5.4). Although the respondents had not been able to fully test the software, respondents believed that the tool had *"potential to do much of what one wants"* (E- and SE-pair 1), but that it required training (response from a majority of the respondents). *"It's not just to sit down with this and start drawing an office"* (SE-pair 1). Another respondent expressed a slight dissatisfaction with the tutorials and that the person in the tutorial was talking, and moving too quickly.

Respondents further expressed the need for furniture and dimensions to be correct, and that if SketchUp was able to entail such details then the software was likely to achieve the principle. *"If talking work-environment, then there are those that are particularly fuzzy about that it is the correct dimensions and the correct appliances* *and such" (E-ind 3).* Another question that was asked by respondents was whether the program was compatible with what Architects were using.

Given that SketchUp Pro was known to be exportable from file-formats such as DWG, (compatible to a common CAD-program used by Architects) *(3D Developer Engineer)*, as well as being used by Architects during the early design stages *(Architect, CAD-expert)*, respondents were informed that the software could indeed be capable of this.

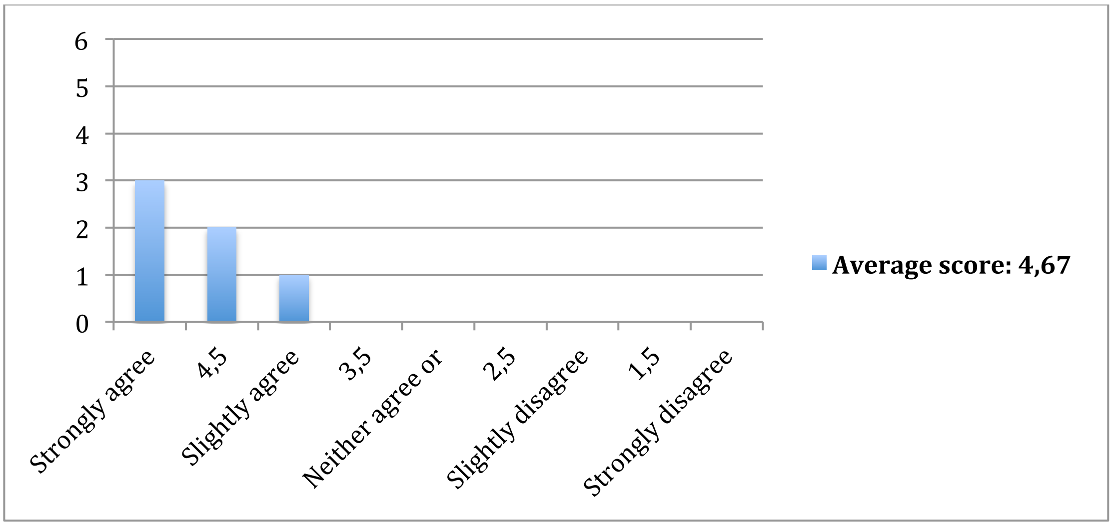


Figure 5.4) The mode value of the scored principle "Successful Task Performances".

Quality of Outcome *(The end-result reaches the expected outcome):*

The next highest scored principle was the software' quality of outcome (see figure 5.5). The quality of outcome seemed to be interpreted by the respondents as both what the software was capable of, in terms of its quality potential, and the actual outcome of the task performances they were witnessing during their own actions.

Respondents saw a potential in the software ability to visualize in 3-D. *"It is a professional way to illustrate"* (E-pair 2). However, respondents believed it was difficult to score when they had seen so little of the program yet. Other aspects that influenced the score were by some the potential complexity in adapting products to the specific product details. Other scores were directly related to the outcome of their own task-performances. Referring particularly to a painting task, respondent E-ind 4 conveyed: *"It did not turn out as I planned, plus I don't know what happened".*

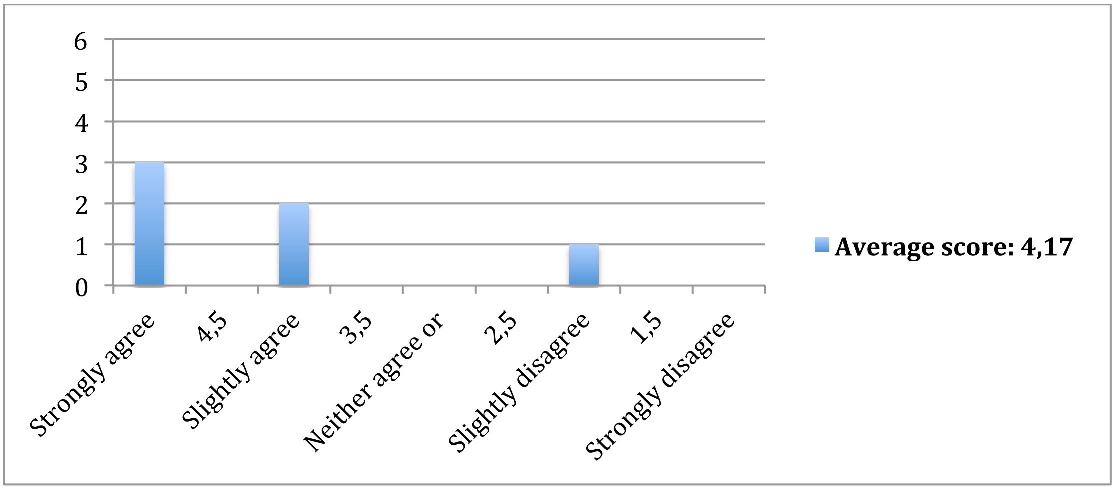


Figure 5.5) The mode value of the scored principle "Quality of Outcome".

Learnability *(The design-tool is requiring little effort and training to reach a competent level of performance, e.g. visual clues and terminology make the interface understandable, comprehensible and learnable):*

Learnability was, sadly, the one principle that received the lowest rated score by the respondents (figure 5.6). The low scores was explained to be due to the effort and training required for working in 3-D, some even mentioned education, as well as in able to achieve a *"feel for how the mouse and keyboard is influencing"* (SE-pair 2). The same respondent further conveyed: *"It does of course exist a certain possibility. But it still requires that you put your mind into it"*.

An individual Ergonomist commented that after a drawing action, it became more comprehensible. Another Ergonomist neither agreed or disagreed and elaborated that *"Some parts are difficult to achieve after just a short intro"* (E-ind 4).

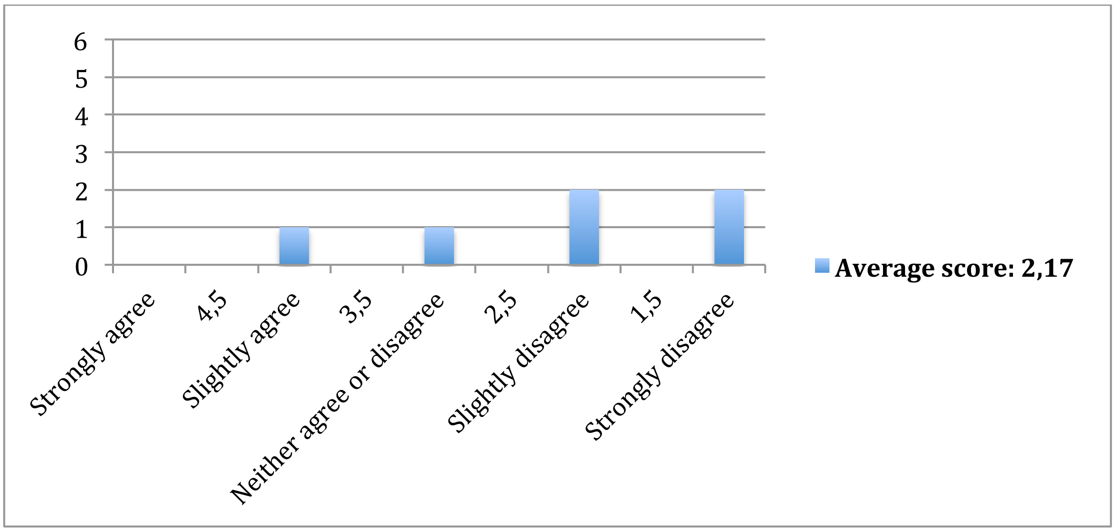


Figure 5.6) The mode value of the scored principle "Learnability".

Memorability *(The methods to achieve tasks are easily memorable):*

Memorability received one of the lowest scores (see figure 5.7), particularly by the pairs where 3 out of the 4 slightly disagreed that the methods to achieve tasks were easily memorable. Respondents conveyed that it "*initially*" could be difficult to remember functions, but that once learnt, you'd probably know it (E- and SE-pair 1). *"I think it requires much training"* (E-pair 2). She further elaborated that it had to do with kinesiology, with motion. *"Yes, until you get the feel for it"* (SE-pair 2). A higher score was rated by one of the Safety-engineers and the two individual Ergonomists. *"Yes I would say that it is"* (E-ind 4) (easily memorable) ... *"after making some mistakes, then I seem to remember"* (E-ind 4).

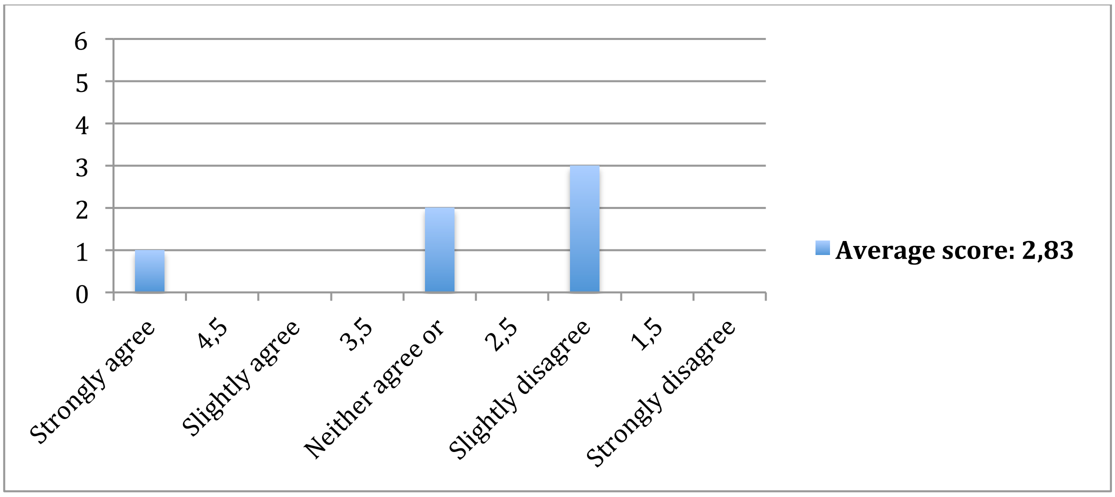


Figure 5.7) The mode value of the scored principle "Memorability".

Speed of Performance *(Desirable tasks are achievable at a high speed):*

Most respondents indicated that a software' speed of performance was difficult to assess, partly due to the short exposure time and all of the unpredictable technical aspects such as poor connection (see figure 5.8).

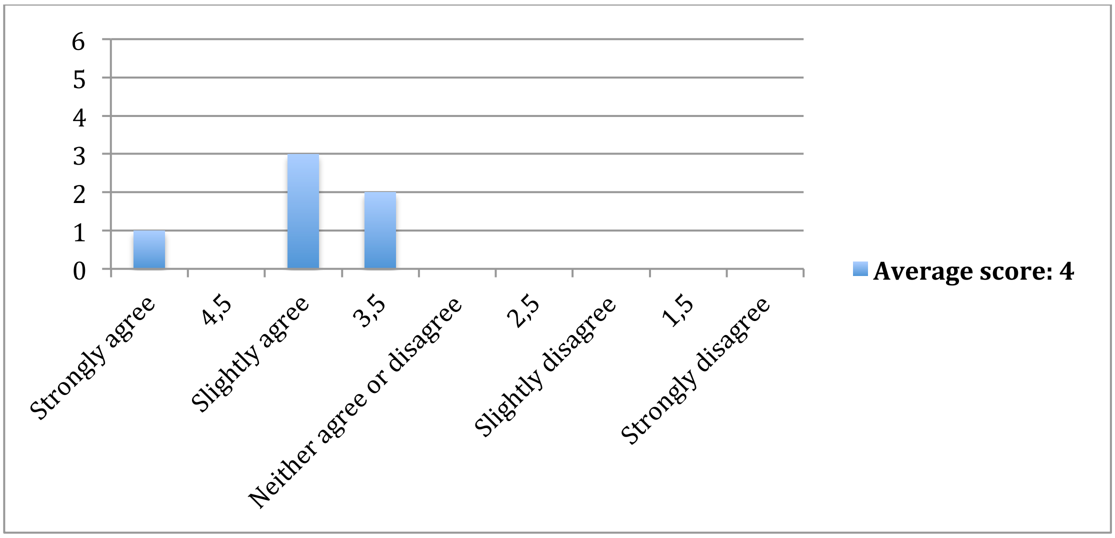


Figure 5.8) The mode value of the scored principle "Speed of Performance".

Error Prevention *(The software help the user recognize, diagnose and recover from errors made, within a timely and effortless manner):*

Respondents that felt able to score slightly agreed that the software helped the user recognize, diagnose and recover from errors made, within a timely and effortless manner (see figure 5.9). Respondents were particularly referring to the *edit* and *Undo* button. *"Provides feedback. I feel like it could have had a better recovering button"* (SE-pair 2). The other pair of respondents felt unable to score the principle since *"we never ended up in that situation .. or was not called upon to correct errors"* (SE- and E-pair 1).

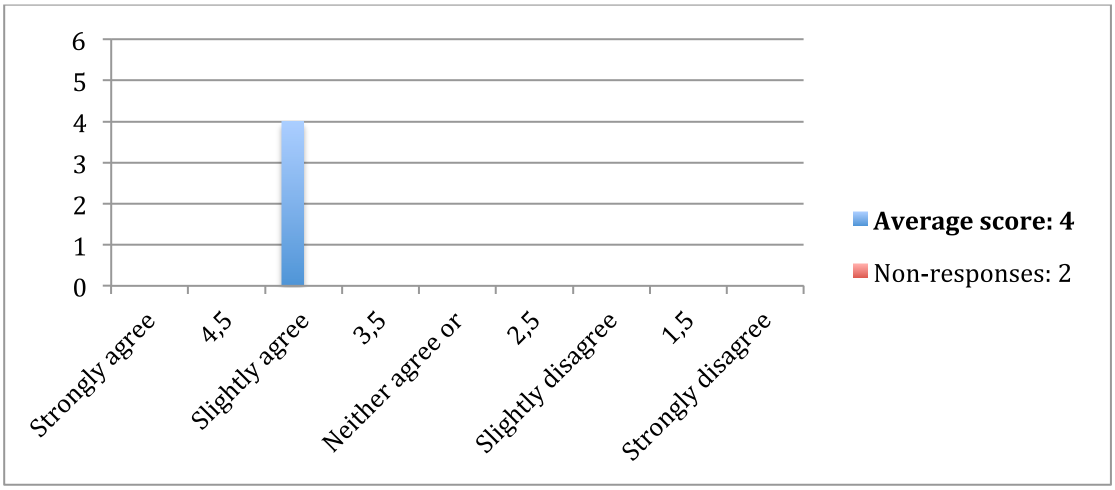


Figure 5.9) The mode value of the scored principle "Error Prevention".

Satisfaction *(You experience satisfaction with functions and features of the software, including the support in performing the desirable tasks):*

Aspects that influenced respondents' level of satisfaction with the software varied between individual respondents as well as within the pairs (see figure 5.10). *E-pair 2* believed that the lack of time and training in attending to the software played a big part in her lack of satisfaction, even frustration, with the software: *"I actually think the program is really good. So it is because of one's lack of training. It become like a presentation of a good product"*. Other respondents expressed similar concerns, and expressed concerns about the required training and potential time-consumption. Difficulties in furnishing, placing and rotating furniture were other experienced drawbacks, including the lack of correlation between the presented toolbars in the tutorial with the way it was truly presented within the program. Yet overall, respondents scored relatively neutral leaning towards a positive direction.

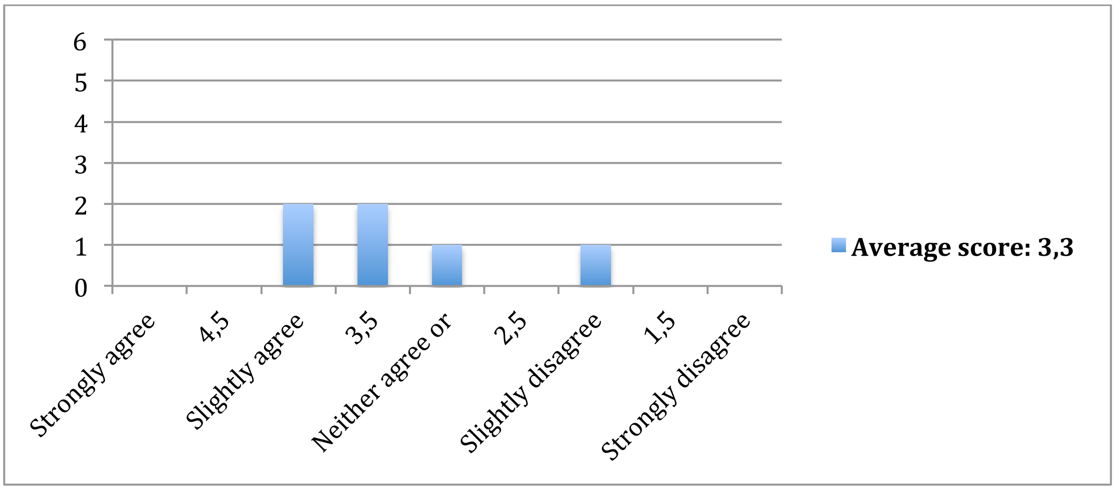


Figure 5.10) The mode value of the scored principle "Satisfaction".

Searchability & Interference of User Manuals *(Online user-manuals within the software are easily searchable while not interfering with the tasks):*

A couple of the respondents reacted to that the video tutorial presented the so-called toolbar within the drawing template vertically, rather than horizontally, which was the case within the tested drawing template. This resulted in confusion and an extra-required effort searching the tools during the usability testing. Others expressed a desire that the user-manuals was available in Swedish, *"particularly for 55+"* (SE-pair 2). *E ind 4* was particularly satisfied with the so-called Instructor tool. *"I thought the instruction while drawing was the most sensible"*. See figure 5.11.

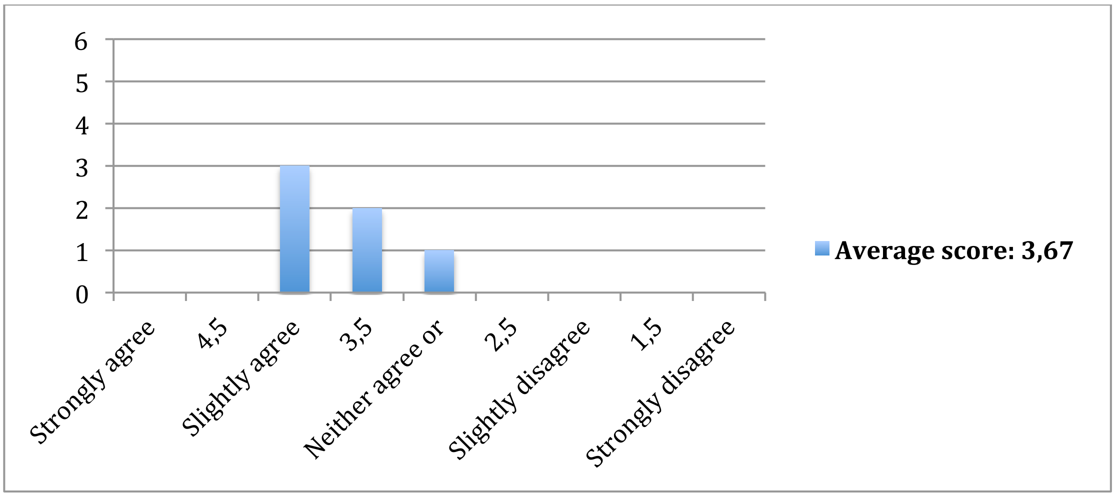


Figure 5.11) The mode value of the scored principle "Searchability and Interference of User Manuals".

Simplicity *(The design-tool is intuitive and guessable, e.g. only a few number of actions are required to perform tasks successfully. Vocabularies are few, familiar and consistent):*

"Most but not everything", responds E-ind 3. Another respondent explained that it could be due to his unfamiliarity with Mac computer. *E-pair 2* expressed a desire for the software to be available in Swedish, elaborating that it would affect its simplicity. There are *"many features"*, expressed SE-pair 2. *"Takes a long time to learn the details"* (SE-pair 2).

E- and SE-pair 1 believed it lacked intuitiveness: *"Symbols are not always easily-understandable.. not always linked to performance"*. See figure 5.12.

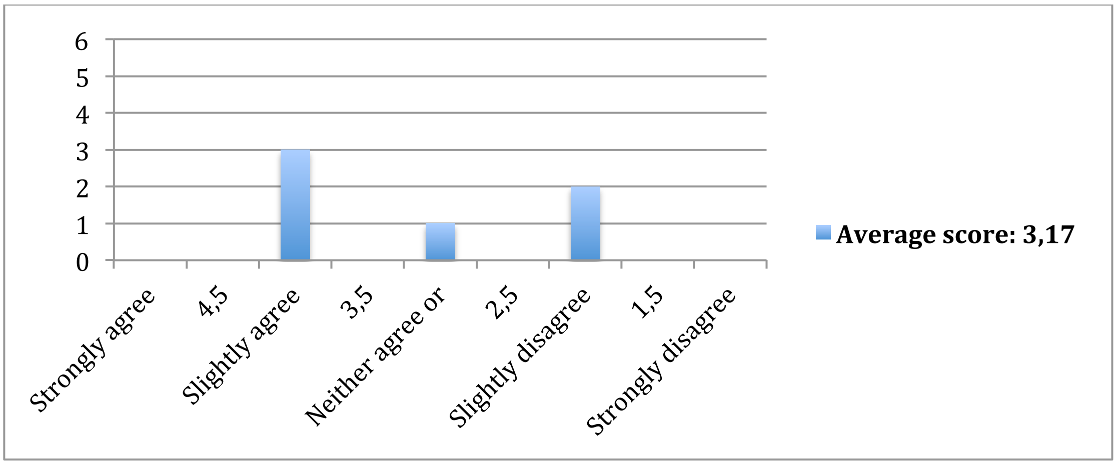


Figure 5.12) The mode value of the scored principle "Simplicity".

Feedback *(Informative feedback is given on performance):*

Respondents' scorings varied from strongly agreeing to strongly disagreeing that informative feedback was given on performance (see figure 5.13). *"You all the time see what happens"* (E-ind 3). "*Once you've learnt what the symbols mean"*, says E-ind 4. The other pairs were more hesitant, and could not pinpoint or memorize any instance where feedback was given.

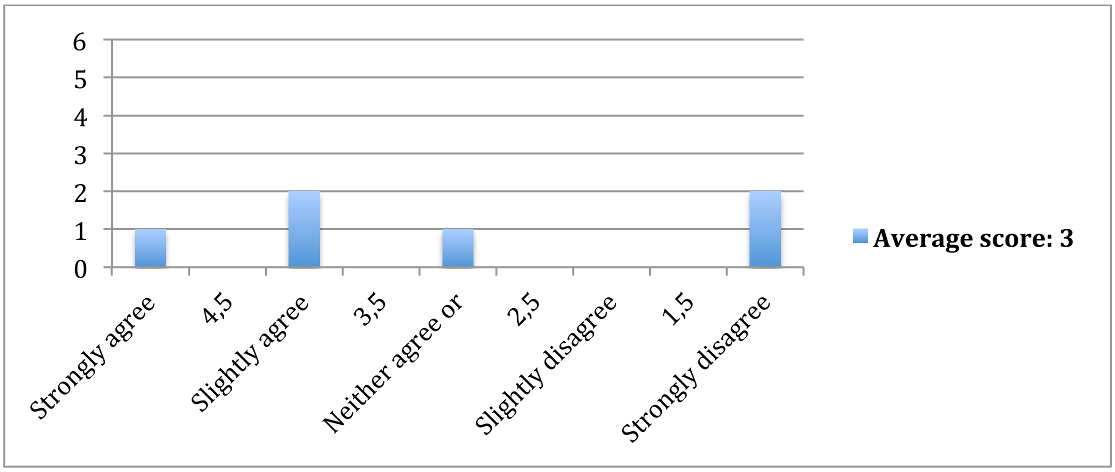


Figure 5.13) The mode value of the scored principle "Feedback".

Language *(You are satisfied with the use of language in the design-tool):*

Most respondents were reasonably satisfied with the language of the software (see figure 5.14), but some were expressing a preference for a Swedish-speaking version, or experienced unfamiliarity with some of the words. E- and SE-pair 1 referred to the video tutorials and expressed a general dissatisfaction with the speed and amount of information conveyed by the instructing voice. *"It was fast, it was hard to follow"*.

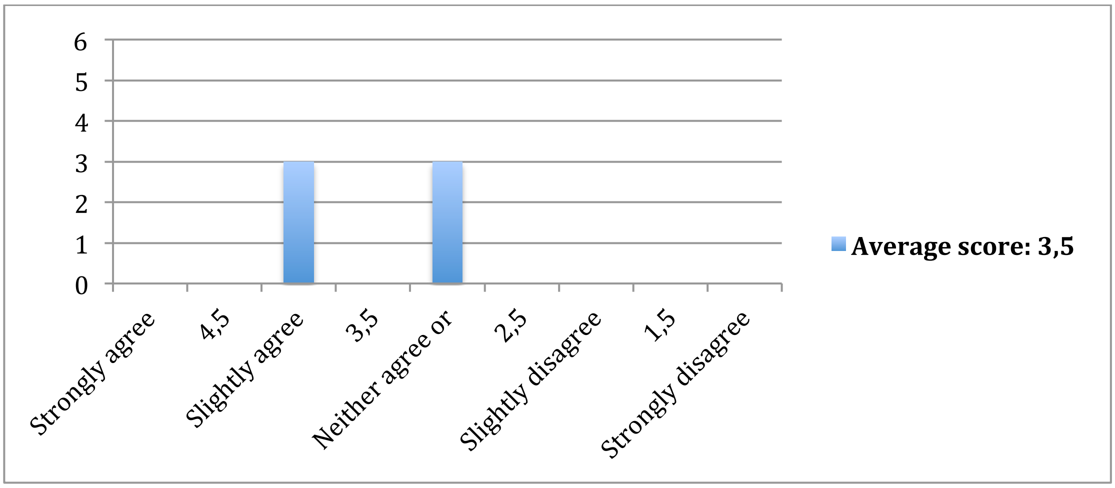


Figure 5.14) The mode value of the scored principle "Language".

5.2.4 Observations During Pair Testing

Both pairs of Safety-engineer and Ergonomist seemed to take turns evenly in controlling the software. The other person not controlling the software was actively engaged in assisting the person controlling. A pattern was seen that in cases that someone experienced difficulties or was stuck, the other person would take over. No one profession seemed to be dominating.

5.2.5 Additional Themes

Cost

Respondents were informed about the cost of the software and consulted about whether they thought the cost could be an acceptable investment for OHS practices.

The two individual Ergonomists believed the software could *potentially* be accepted by OHS practices, particularly by the bigger firms, and particularly if there was a strong customer base. *"..Then I absolutely believe so"* (E-ind 4). One Ergonomist further elaborated that the fact that OHS practices quite rarely get involved in the tasks of workspace design could affect this.

The pairs were less confident and argumenting in terms of *total* costs; i.e. not solely the cost of the software, but the cost of training and in implementation. *"The cost of the software is extremely small compared with the cost of the hours required to learn it"* (E- and SE-pair 1).

The other pair had a similar perspective: *"It is not cost effective. If I were to do a report and attach a sketch of this, then it takes a whole day if sitting and making the drawings with[…] it goes much faster if I sketch into a sketchpad, then, how I want it"* (SE-and E pair 2).

Time to Learn

Respondents were asked about the expected learning time required for them, if they were to use the software for the proposed purpose. Respondents' answers varied from half a day learning time to as long as one to two weeks. Respondents elaborated that it could take time to achieve a certain level of competency required to feel confident with attending to the software, particularly in a presentation and project group scenario.

An Ergonomist commented that: "*It depends how many tasks you get. I can imagine that if one gets individual rooms, then it's easier"* (E-pair 2). Another respondent;

Safety-engineer, seemed significantly overwhelmed by the task of furnishing and building an entire office, without an initial draft from an Architect.

Improvement Potential

During the evaluation stage of testing different software the evaluator constantly faced the controversial issue of *simplicity* versus *functionality*. Design-tools were observed as either *simple*, or with high *functionality*, but rarely both. Other contributors (CAD-expert) similarly illuminated that there is a direct contrariety between the parameters functionality and simplicity when dealing with design-software. For these reasons partly, respondents were asked to reflect on improvements they would like to see within the design software. They were further confronted with the choice of prioritization between simplicity and functionality and asked whether they would prefer a software that was:

1) Easier (but likely with less functionality)
2) With more functionality (but likely more advanced)

E-ind 3 expressed it hard to *set* any functions, since the alternative to 3-D software during workplace design projects is not so good; that working with two-dimensional blueprints has put her in the role of an interpreter to the company's employees. *"Most people are not accustomed to seeing a drawing and think it into three-dimensional […] so from a flat drawing to get it as three-dimensional, that is something that feels very important"* (E-ind 3).

E-ind 4 believed in multimodality, e.g. the possibility to choose a simpler or more functional layout depending on each professions' competency and need of the software. *E-* and *SE-pair 2* expressed a priority for an easier software, and that certain functions like paint, material, interior walls and floor material could be down-prioritized. *"You only really need to see the building rough"* (SE-pair 2). The pair further contemplated about furniture, and that achieving the accuracy in customized furniture would likely require a complex design-tool. The pair also thought about an alternative: to make the coordinates visible; e.g. the dimensions of furniture in relation to the room.

How *SketchUp* can facilitate the process of visualizing and communicating blueprints of future offices

All respondents agreed that the software could facilitate in the process of visualizing and communicating blueprints of new or renewed offices. They expressed that the functionality of 3-D could increase the company and its employees' understanding of the new environment and illuminate any points

OHS practitioners are trying to make. Respondents referred to the ability to visualize and assimilate reality by moving and walking around in three-dimensional space, communicating space utilizations by applying measuring tools, illuminating the correct height by including human models into the environment, etc. *"Risk assessment during changes"*, elaborated SE-pair 2. *"I also believe it saves time […] To constantly photo shoot and show what you mean"* (E-ind 4).

In addition, the design-tool was believed to facilitate the communication and collaboration between OHS practitioners and Architects. *"I see that this could be an educational communicative tool between the Architect and OHS"* (E- and SE-pair 1). *E-pair 1* further referred to external OHS practices and how they may be consulted too late in the process after the Architect already has the plan all set. *E-ind 4* elaborated that by learning the functionality of the software and how to draw that one could achieve a *"common language"* between the Architect and OHS practitioner; a language closer to that of the Architect, in which could facilitate the communication between the professions.

The Tools' Applicability to Safety-engineers and Ergonomists

Some respondents indicated that they were doubtful if the design-tool would be applicable as part of their role during workplace design.

"Isn't is better that Architects apply these programs and does something… a basic draft [...] but that the dialogue between the Architect and us has to exist [...] so that the Architect doesn't just throw together a drawing of an office and then says this is how it should be.. but that one meets with the Architect and comes to agreement, that way gets included and, then they get to maneuver it rather than for us to sit.." (E- and SE-pair 1). The pair further elaborated that they had more of a consultant role for layouts, that their operative roles consisted of many other job duties than workplace design. "*The time does not really exist to learn a design-tool like this one"* (E- and SE-pair 1). Another Safety-engineer expressed the following: *"Actually, I don't fully see the need for this program in my job. I don't work with layout in that aspect, but more in terms of ventilation"* (SE-pair 2)

5.3 Summary of Results

With the respondents' previous weightings of the principles and the scorings of the Reference Concept (*SketchUp*), a total applicability of the tool to the practitioners involved could be calculated via a Concept Scoring Matrix.

		A *Concept*		**B** *SketchUp*		**C** *Concept*	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Successful task-performances	4,33			4,67	20,22		
Quality of Outcome	4,33			4,17	18,06		
Learnability	4,83			2,17	10,48		
Memorability	4,17			2,83	11,80		
Speed of Performance	4			4	16		
Error prevention	5			4	20		
Satisfaction	4,5			3,3	14,85		
User-manuals	4,17			3,67	15,30		
Simplicity	5			3,17	15,85		
Feedback	3,83			3	11,49		
Language	4,83			3,5	16,90		
Total Score					**170,95**		
100%					243,65		
Applicability					**70,16%**		

5.3.1 Concept Scoring Matrix with Comparative Concepts

The following table represented the *evaluator's* scores of each of the concepts, and was recalculated based on the weightings derived from the respondents.

		A *RoomSketcher*		**B** *SketchUp*		**C** *Floorplanner*	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Successful task-performances	4,33	3	10,82	5	21,65	2,5	10,82
Quality of Outcome	4,33	3	12,99	4.5	19,48	2.5	10,82
Learnability	4,83	3.5	16,90	3.5	16,90	4.5	21,73
Memorability	4,17	4.5	18,76	3.5	14,59	4.5	18,76
Speed of Performance	4	4	16	4	16	3	12
Error prevention	5	4	20	4.5	22,5	3.5	17,5
Satisfaction	4,5	2.5	11,25	4.5	20,25	2.5	11,25
User-manuals	4,17	2.5	10,42	4.5	18,76	4.5	18,76
Simplicity	5	4.5	22,5	3	15	5	25
Feedback	3,83	2	7,66	5	19,15	4	15,32
Language	4,83	5	24,15	4	19,32	5	24,15
Total Score			171,45		**203,6**		186,11
Rank			3		**1**		2
100%			243,65		243,65		243,65
Applicability			**70,37%**		**83,32%**		**76,38%**

6.0 Discussion of Result

6.1 *Which computerized design tools for facility-layout existed on the market that attained a level of usability required for the inexperienced users of CAD?*

Several potentially suitable design-tools were identified as part of this study (4.1.3). All were compared to the basic requirements outlined in section 4.1.2; requirements that were considered essential in order to fulfill the tools' purpose of use; for OHS practitioners to communicate architectural blueprint proposals to the end-users of the new or renewed workplace facility. Thus, the basic requirements helped disqualify tools that would likely be disapproved by the potential users, e.g. due to costs or language, or that could not fulfill the most basic functionality needed to reach the end-goal. Three tools were further evaluated. These were preceded due to the *belief* that they not only reach the requirements of functionality, operative systems, cost and language, but that they were suitable for *inexperienced CAD users*. However, in order to truly reveal their suitability, the tools were evaluated more thoroughly.

The usability definition itself sheds light on three interwoven aspects to be considered: *"To enable users to* ***achieve goals*** *and* ***meet needs*** *in a* ***particular context*** *of use"* (ISO, 1998). Inexperienced users have specific *needs* to be met to enable them achieving their goals in mind. A software' ability for *successful task performances* alone, does not help the intended users to achieve goals. A combination of enabling principles focused on users *needs* does. Successful task performances make goals achievable, but that does not help if the intended users still cannot successfully achieve them. Respondents expressed some very legitimate needs for the population such as a need for simplicity and learnability. Other *needs* of inexperienced users were identified and turned into principles as part of the evaluation matrices.

The concept screening and scoring matrices thus interweave principles as part of the usability definition, with criteria considered essential for the applicability to the proposed user population. As such, it illuminated:

- The three design-tools' attained level of usability for the *inexperienced* users of CAD, individually and in comparison to one another.
- The three design-tools' applicability to the proposed user-population.

6.1.2 Results of the Initial Evaluation

The results of the evaluator's initial evaluation of the tools revealed that *SketchUp* generally rated higher on usability for inexperienced users than the two other design-tools, particularly in areas that enabled the user to "achieve goals", or more precisely made goals achievable. As for enabling the user to "meet needs", *SketchUp* scored higher in error prevention, user manuals and feedback, something known to have an impact on inexperienced users of visual displays (Schneiderman and Plaisant, 2010). Results from the weightings showed how the principle of error prevention was highly appreciated by the respondents. Whereas the significance of user manuals and feedback were more controversy, participants during the usability sessions that were faced with their absence implied a general *need* for them. *The Instructor tool* function in SketchUp, predominately responsible for informative feedback during task performances, was not only considered significant, but a necessity during the testing phase. The evaluator's experience was that it contributed to increasing the tools' overall learnability by providing the informative feedback for correct actions, preventing wrongly performed actions while demanding low reliance on memory. It helped support the inexperienced user, in which relies heavily on information available in their environment. (Osvalder and Ulfvengren, 2010). On a less positive note; the reliance on an instructor tool for task performances could be viewed as a compensation for an intuitive and guessable interface (Schneiderman and Plaisant 2010; Jordan, 2002). In this aspect, the principles of simplicity and learnability are really impartible and highly dependent on one another.

SketchUp, not showing a single score below neutral, differed substantially from the two other design tools. Although these tools were considered simpler, more memorable with an advantage in language, they scored lower on criterion such as error prevention, feedback and user-manuals. Results of the tables indicate that while simplicity comes a long way, other criteria of relevance to novice CAD-users could make a more complex tool *appear* simpler, enabling the user in employing the software with greater ease and confidence. SketchUp was undoubtedly the most complex tool of the three, but mirrored functionalities that helped the user recognize, diagnose and learn to attend to the tool. It supported the user in achieving the overall goals of e.g. dimensional accuracy, providing the visual feedback through reference points, midpoint and edge-points, a functionality lacking in the other two "simpler" design-tools.

For what it is worth, the total ranks in the Concept Screening Matrix showed how SketchUp was rated first, Floorplanner second, and RoomSketcher third. Concept Scoring Matrix, inclusive of the user-populations' weightings of each criterion, showed the same result. The Concept Scoring Matrix further revealed that neither of the tools could attain a 100% score, but that all reached a percentage of at least 70%, less than 30% away from being fully attained.

6.1.3 SketchUp

SketchUp, being the tool highest rated by the evaluator, was preceded for usability testing and scored by the six participants. In comparison to the initial results above, SketchUp dropped almost 14% in total score when rated by these participants.

The comparative scores revealed the criterion that differed the most, versus the least, during evaluations. While *simplicity* and *speed of performance* were rated identically, the average score of all other criterion were lower in the usability sessions. Criterion such as *feedback*, *learnability* and *memorability* differed in up to two rating scales. Lack of time and training seemed to be the recurring theme. Yet, even participants that seemed the most reluctant to the software's ability to achieve certain of the principles saw a "potential" for their achievement, but imagined a steep learning curve, requiring much effort.

Respondents believed that a tools' memorability was secondary to a tools' simplicity. Rather than memorability, a design tool's interface should prioritize simplicity and intuition. Respondents indicated that the software achieved the principle of simplicity to some degree, but not fully. With the many available functions and symbols, the software appeared more complex, all of which were not considered intuitive and standardized. A suggestion was made for multimodality; adapting the visible functionality to the user. A suitable adaptation for a novice user was interpreted to be about a simpler layout consisting of fewer functions and symbols. Wickens et al. (2004) further stressed how fewer options and tools simplifies task performances and reduces risk for error in the novice user. In SketchUp, such a multimodality function appeared possible. Through a predefined toolbar consisting of only the most common and basic functionality relevant for a beginner, the "getting started" toolbar was a recommendable feature by default. As users advanced, additional tools could be added onto the toolbar. However, during the usability testing, the "getting started" toolbar was the one already displayed.

Another frequently raised topic was language. Language was weighted highly by the respondents. Respondents believed that a Swedish-speaking version of the software could increase its overall simplicity. This particularly referred to tutorial videos, found in SketchUp's own learning material. Respondents were informed about an extended network of Swedish-speaking tutorial videos throughout the web. However, these were not administered by SketchUp and therefore not introduced during the usability sessions. As for the tutorials administered by SketchUp, the tutorial voice was considered too fast-paced for several of the respondents. Although the language of instruction was contributing to parts of it, respondents reacted to the amount of information conveyed during short amounts of time and how it challenged their focus. This, in combination with the toolbar's inconsistent view (refer to section 5.2.3), could have caused that respondents could not fully remember all steps to achieve task performances. This corresponds to theories of novice users' limited capacity for new incoming stimuli due to high demands on working-memory functions during first time encounters with a task or interface (Wickens et al., 2004). However, user manuals were not only consisting of video tutorials, but text manuals, practical self-paced tutorials and an interactive instructor tool. Regardless, respondents appeared to prefer video tutorials and practical tutorials to text. This further stresses the importance of user-friendly practical illustrative tutorial guides.

Lastly, the software' ability for error prevention was another highly appreciated principle in which most respondents agreed to its achievement. Its' ability for error prevention depended highly on feedback and recovery functions. This meant that respondents that were experiencing *minor* or *major* errors, in which occurred to most participants, were able to identify and recover from the errors made. Still, *fatal* errors were also observed. This was characterized by that respondents abandoned tasks because they were unable to diagnose the errors. However, even during these stages, most respondents were able to return to a previous state or move on to other tasks.

6.1.4 Interpretation of Diverse Results

As shown, some differences in results were evident both between participants and between usability sessions and the initial evaluation. An interpretation of these differences was the level of controlled versus flexible testing conditions, differences in evaluation time, individual versus pair testing, in addition to age and level of acceptance.

Firstly, usability sessions differed from the initial evaluation, which took place over a longer period of time and more in-depth than the usability sessions could, for practical implications. The controlled testing conditions under the usability sessions made the task of identifying influencing factors quite distinguishable. As mentioned by one of the Ergonomists; some parts were difficult to achieve after just a short intro. What respondents were facing were first encounters, not only with *SketchUp*, but with *any* design tool. Respondents were faced with new tasks, which evolved into additional new tasks, each of these tasks under time constraints. Occasionally, these time constraints resulted in interruptions during task performances, an inability to complete tasks. First time users' unsuccessful task performances could trigger decreased confidence in their ability to attend to the software, and as a result trigger decreased satisfaction and an increase in anxiety levels (Schneiderman and Plaisant, 2010).

Participants during pair-sessions had both advantages and disadvantages. Advantages because they could collaborate with one another, disadvantages because they were two people sharing one screen, potentially facing an increased social pressure, while not being given as much of a chance to individually test and get a *feel* for the software. Getting the feel for how the mouse and keyboard was influencing was by the participants considered a necessary skill when applying a drawing tool like SketchUp. Such a statement is further supported by theory (Schoonmaker, 2003). Whether these influencing factors had a significant impact on the individual versus pair participants experience with the software is unknown. Pair- and individual sessions in this study were too few and insufficient to draw any conclusions. Nevertheless, a quite consistent pattern was seen that participants during the pair-sessions were less satisfied with the tools' overall usability for inexperienced users, such as the software's learnability, memorability and simplicity. The two individual Ergonomists were noticeably more confident in these aspects and provided higher scores. On a bigger scale, this could imply that learning to attend to CAD software is more efficient when done so individually, rather than in pairs.

Evidently, keeping objectivity is important, particularly when facing so many influencing factors during usability sessions. The score of 70% and 83% could represent how the software, despite its slight complexity for first time users, to some degree still achieves the Usability principles relevant for inexperienced users of CAD. The results also illuminate the potential issues inexperienced users of CAD may be experiencing when interacting with the interface for the first time.

6.2 *To which degree was any of the identified design tools applicable to OHS practitioners?*

The Concept Scoring Matrices gave an indication of each tools' applicability to inexperienced users and OHS practitioners alike. While one tool was clearly favored over the others, each design tool had its share of pros and cons that as a result could advantage and disadvantage the OHS practitioners in different ways. In contrary, tools differences was particularly evident in their level of achievement in areas of *Successful Task Performances* and *Simplicity*, presenting a pattern that consistently marked the controversy between functionality and simplicity.

The study has shown that in order to be fully applicable to OHS practitioners; design-tools must reach the desirable functionality relevant for achieving the goals of its use, while simultaneously mirroring an interface suitable for inexperienced users. It was previously conveyed how a CAD-expert strongly found such principles conflicting in a CAD program. Wickens et al. (2004) described how principles sometimes "conflict" or "collide". The personal experience of searching applicable tools has been that tools rarely *fully* achieve both functionality and simplicity, and that when they do; they only do so to a certain degree. The 70/83% score of *SketchUp* surely reflected this. Thus, the question must be asked: Is it achievable? If achieving both proves unattainable, is the most realistic solution to strive for a balance through a prioritization of a tools' achievement of either *goals* or *needs*?

6.2.1 Applicability to Users' Tasks and Goals

The HTA-analysis in section 4.2.4 reflected some of the most realistic tasks to be fulfilled through the current process of workplace design by OHS practitioners such as Ergonomists and Safety-engineers. The HTA-analysis was a suggestion, not a recipe, and reflected much of the information conveyed during the two qualitative interviews with respondent A and B. While parts of it were describing an already existing process, the rest was representing the *ideal* adapted to the current situational circumstances of OHS practitioners' present involvement. All in all, the purpose of the HTA process was to achieve the overall goal of presenting, communicating and visualizing the architectural blueprint to the end-users of the new or renewed work-facilities, a process resembling a *participative approach*. The process of which this was achieved was much less determined and thus formulated in a manner that expressed a degree of flexibility.

The HTA confronted several potentially significant tasks for OHS practitioners to practice in order to fully fulfill the end-goal of participative design. Presenting, navigating and manipulating the 3-D built environment were some of them (Zandin, 2001). Other tasks were related to non-detailed or detailed environments such as the inclusion of equipment, furniture and correct dimensional values. Participants in this study favored several of such tasks e.g. the ability to entail correct dimensional values and appliances, manipulating an existing environment such as furniture, and rendering the 3-D environment from different angles e.g. top-view. However, with functionality comes complexity, an experience most participants were not exempt from during the usability testing of *SketchUp*. While participants thought the rendering function of 3-D view was straightforward, requiring little effort, a couple of participants felt less confident about the closed-up visualization tool of *walk-around*. While such a feature may not appear crucial, Zandin (2001) stresses its significance when communicating a detailed work-environment. Also, in SketchUp where full flexibility in furniture was achievable, manipulating or building furniture from scratch would surely be a more complicated process than downloading preexisting furniture into the model. Overall, simplicity was believed to depend on the complexity of the tasks to be performed e.g. individual rooms over entire office buildings, rough over detailed environments, etc. In other words, CAD-tools are not the only thing prone to complexity, tasks are.

Therefore, in order to sacrifice or prioritize functionality, one needs to identify the essentials; e.g. the necessary tasks. Only once the essentials have been identified, can a conscious decision be made about which tasks that is sacrificial, and which aren't. This further demonstrates how complexity and lack of simplicity are highly influenced by:

1) The tasks performed within the software.
2) The functionality demanded of the software.

Participants that were faced with the issue of simplicity versus functionality did not take the prioritization lightly. Functionality related to furniture, 3-D view and precise dimensions was set high-priority. However, a couple of participants indicated that coordinates were more important than the specific details of e.g. a piece of furniture. According to the same sources, environments only needed to be made rough. However, Zandin (2001) expressed how designing a rough environment could accomplish many of the important aspects, but not all. Details such as working techniques, height of furniture and placement of equipment could be less achievable in a non-detailed environment (Zandin, 2001).

Architects as Primary Users?

It's a challenge having determined how tasks can affect simplicity of CAD-tools, and knowing participants' striving after a simpler and more learnable tool while desiring software able to achieve *successful task performances* and *quality of outcome* stands in contradiction. Respondents illuminated the highly relevant proposition of whether Architects were part of the solution. The idea of building entire offices from scratch understandably overwhelmed certain participants. The most ideal would be if Architects delivered their initial proposals in 3-D, something that they according to CAD-expert should have the prerequisites to do. The flow, cost-efficiency and time were all thought to be positively influenced by such an initiation.

After all, why should OHS practitioners play the role of an Architect when there already *are* Architects? If the collaboration and dialogue existed between OHS practitioners and Architects, would OHS practitioners need to manipulate the design-tool at all?.. For the sake of participatory ergonomics, the answer is firmly yes. The OHS practitioners should manipulate the design-tool because the whole point of a participatory approach for OHS practitioners is to increase end-users' understanding of the work-environment, from an occupational health and safety perspective. Architects cannot take on this role, and have not been seen to take on this role previously. The software should be a medium for OHS practitioners to illuminate their views while involving the end-users. Yet, if Architects delivered their proposals in 3-D, OHS practitioners would still be exempt from the extensive task of designing a model from scratch; something that would decrease the required learning time, implementation of, and potentially acceptance of a design-tool. Since time and costs were considered interconnected, anything shortening learning time and implementation would likely also decrease the total cost of and increase the likelihood that OHS practices would approve a design-software.

6.3 How SketchUp can Facilitate the Process of Visualizing and Communicating Blueprints of Future Offices

It has been shown that respondents believed SketchUp could facilitate the process of visualizing and communicating blueprints of future offices. The functionality of 3-D, the functionality of rendering different views and the functionality of displayed measurements including the insertion of human models were examples of highly appreciated components that were believed to contribute to the process. The rendering features were thought to increase end-users' understanding of the work-environment as well as save time, due to constantly being able to show and illuminate the points OHS practitioners were trying to make. This is consistent with previous research on the topic that elaborated how increasing the company's understanding could result in both time and cost savings in the longer run (Zandin, 2001).

Participants seemed to place high value to the collaboration with Architects. By learning to attend to a CAD-software, OHS practitioners were thought to achieve a common language with the Architect while enhancing the communication between them. The software's highly scored functionality and quality were further implied valuable for achieving the level of standard appreciated by Architects. With the software's known compatibility with Architectural file formats in addition to being well known and initially applied by some Architects, the software is, as suggested by respondents, also likely to be successful as a communicative tool between OHS practitioners and Architects. The increased collaboration, in turn, was believed to result in a better inclusion of OHS practitioners much earlier in the process of workspace design projects. With the supporting research of getting involved early in the design process (Seim and Broberg, 2009; Antonsson, et al., 2011), such an aspect was considered extremely valuable.

7.0 Discussion of Method

The study included various methods. The study's design and methods are here discussed in terms of their internal and external validity and reliability.

7.1 Internal Validity

The Evaluation of Design Tools

The study consisted of two distinguishable evaluation phases; the initial evaluation and the usability testing. Following some recommended steps of a so-called *interaction analysis*, applicable tools were first explored and tested by one evaluator solely; i.e. the author of this paper. Commonly referred to as the "expert" method, such a method could have its flaws given its distance to "reality" (Osvalder et al., 2010). Although somewhat experienced with interface design and cognitive ergonomics, the evaluator was inexperienced with CAD-tools, which for the purpose of this study had its pros and cons. Firstly, the initial evaluation of tools could be prone to interpretation errors, such as a failure to discover available functions in software, failure to acknowledge feedback, among other drawbacks. In order to avoid this effect, different sources were consulted such as program facilitators, user communities and online forums. However, being an inexperienced CAD-user also brought its advantages, particularly for the sake of evaluating a tool's suitability for inexperienced users. Thus, all the evaluations performed in this study revealed results that reflected the experiences and reactions from the novice, inexperienced users of CAD. Moreover, Concept Decision Matrices were chosen in order to maintain objectivity during the selection process and a rationale behind chosen concepts (Ulrich and Eppinger, 2008).

Although all three tools were evaluated, only one was preceded for the usability sessions with potential users. Respondents during usability sessions already thought their exposure to the *one* software was too scarce for them to evaluate with full confidence. Hence, the evaluation methods differed, resulting in uneven evaluation results. In other words, *Floorplanner* and *RoomSketcher* were not fully evaluated towards the user population. Therefore, their results may not be fully comparative or thorough.

Defining and Choosing Evaluation Material and Concepts

Different sources such as respondent A and B, CAD- and visualization experts were believed to increase objectivity of the evaluation process as well as strengthening the validity of the designed methods. The selection of concepts, the completion of Hierarchical Task Analysis and the selection of criteria's for Concept Matrices were all some very critical parts of the study.

Therefore, respondents contributing to these steps were very specifically chosen based on their ability to provide valid information. Although one may never know for sure how good sources of information a respondent really is (Jacobsen, 2002), each informative respondent were chosen on the basis of their background and expertise, including their own validation that they were suitable candidates for the intended purpose. In addition, results revealed how informants had similar perspectives, in which were seen to strengthen the validity of the information conveyed (Jacobsen, 2002). The information conveyed by respondents was further seen to comply with theory; the theory itself being based of what was considered strong, reliable and independent sources of information. Moreover, criteria chosen for evaluation was selected through a conscious prioritization based on its context of use, the principles most supported by theory and the information conveyed by respondents. Each criterion was further scrutinized and chosen based on several authors' reference to them.

Usability Sessions

Usability sessions were divided into an introduction period, a testing period, an evaluation period and a subsequent interview. This is quite a lot to include into an hourly long session. Therefore, one needs to be clear about and interpret the findings accordingly. While the evaluation performed by these respondents certainly reflected the reactions and experiences from first time users, it may not be credible enough to provide a full picture of the design tool's reached level of usability and so on. Moreover, other influencing factors could be seen to affect the validity of the results, as described in section 5.2.2. However, Osvalder et al. (2010) stresses that usability tests regardless have the potential to provide very valuable data.

Usability sessions were performed either by single participants or pairs. Pair testing's had the potential to produce some interesting results, while strengthening the validity of the evaluation since respondents had a chance to discuss and reflect over the results with one another. From a more critical point of view, this could also be seen to affect the evaluation's validity negatively. Jacobsen (2002) points to that human beings are highly affected by one another and that a person's behavior and expressions can be greatly influenced by other people in our surroundings. This means that a certain risk exist that pair participants were influencing one another, despite their potential conflicting views. Other influential factors related to the pair sessions were briefly mentioned in section 6.1.4, such as a less opportunity to individually get a *feel* for the software.

Method Triangulation

Some different data collection methods were applied during the study, such as qualitative interviews, evaluations and usability sessions, as well as email- and telephone correspondence with both informative and representative users. Jacobsen (2002) mentions how different methodological approaches strengthen the validity of the results of the study.

7.2 External Validity

Generalization

As often is the case in qualitative studies (Jacobsen, 2002), results of the study could contribute to some general theories on the subject based on the output from the participants. As for proving generalizable to a bigger population, the study reflected the typical defect of a qualitative study of quite few participants; much less generalizable to a bigger sample (Jacobsen, 2002). Yet, usability testing runs the advantage given their approach of involving *representative* users (Osvalder et al., 2010). When involving representative respondents, Jacobsen (2002) stresses how the recurring views of these respondents may quite confidently provide generalizable features that relates to a bigger sample of a population. Osvalder et al. (2010) referred to the common guideline of that 75-80% of all of the usability problems incur when 5 to 6 representative users are included in the testing. The 6 participants a part of the usability sessions could therefore indicate that quite a high percentage of the usability problems was revealed during these sessions.

So just how representative were the users? The lack of thorough statistics of OHS practices and practitioners makes such a calculation complex, if not impossible to determine. Section 3.2.3 described the many factors influencing the derived statistics. One of such pattern was nonregistered statistics for *internal* OHS practices. Usability participants during this study were all part of internal OHS practices. Thus, a slight chance exist that the statistics derived were less representative to internal OHS practices. Regardless, when comparing the actual sample to the desirable sample (refer to section 3.2.3, *final selection*), respondents were very close to the representative sample; with 4 out of 6 respondents fully mirroring the described units, only two differed slightly in gender or age. Most importantly, all participants were or had been involved with workspace design and were actively working as OHS practitioners. With four Ergonomists and two Safety-engineers, all inexperienced CAD-users; the results were seen quite generalizable to inexperienced OHS practitioners involved in workspace design.

7.3 Reliability

Data Collection

All of the qualitative interviews and usability sessions were prone to a so-called *interviewer effect* (Jacobsen, 2002); the interviewer being inexperienced with research interviews, and in particular with administering usability testing sessions. The usability sessions' participants were further prone to so-called *observer effect,* despite not being observed in the usual sense, interviewees knew that their screen were recorded throughout the testing period. In a similar way, the tape recorder could have influenced what, how and how much information interviewees conveyed.

Another potential treat to the reliability is the so-called *context effect* (Jacobsen, 2002). All participants a part of this study was interviewed in their own context or environment, e.g. within the same building as their own workplace, thus in their *natural* and safe context. For the sake of preventing some of the technical issues experienced, having had the sessions in an artificial environment adapted to the usability sessions could have had its advantages, particularly for the interviewer.

Analysis

Almost all data collection was of Swedish-speaking sources thus were translated to English when described in this report. This may have negatively affected the reliability of the study since the sentence structure and interpretation of content could slightly differ from the way it was originally conveyed.

8.0 Conclusions

The purpose of this study was to identify some of the existing three-dimensional CAD-tools that were applicable for office layouts, and that reflected a level of usability required for the more inexperienced users of CAD. The study further sought to concretize to which degree any of the identified tools were applicable tools to be used by OHS practitioners, as a means of visualizing and communicating blueprint proposals to end-users of new or renewed office facilities.

While several CAD-tools were identified, only three were found to reach the basic requirements of OHS practitioners' use. Despite being considered the most complex of the three, SketchUp achieved a generally higher rated usability for inexperienced users and applicability to the OHS practitioners. While the other two tools could be considered simpler and more intuitive, they did not, to the same degree, appear to be supporting the user with functionalities to help recognize, diagnose, and learn to draw accurately. Most importantly, they were not seen to possess all the functionalities required to achieve the desirable task performances. By supporting the user in achieving the overall goals of the tools' use, SketchUp were seen to mirror many of such functionalities.

SketchUp was preceded for usability testing among potential users of Ergonomists and Safety-engineers. Results from these evaluations implied that for first time users, the design-tool was considered more complex than when testing it over a prolonged period of time. The lowest rated principles of learnability and memorability could imply a quite steep learning curve for most of these users, particularly for reaching a level of competency necessary to feel confident in applying the 3-D tool in a project group scenario.

Results of the study also indicate that in order to be fully applicable to OHS practitioners, design tools must be able to achieve the desirable functionality relevant for achieving the goals of its' use, while simultaneously mirroring an interface suitable for inexperienced users. Design tools' highest valued principles were the ability to attain a level of simplicity and error prevention, followed by ease of learning and language. While some considered the design-tool quite simple and intuitive, others expressed a desire for a simpler interface. Respondents believed that a Swedish-speaking version of the software, in combination with more learner-friendly tutorial guides and the option of fewer tools and symbols, could increase its overall simplicity. With some tasks being considered more complex than others, results further reflected how CAD-tools' simplicity could be highly influenced by the tasks to be performed within the software. The contrariety between parameters of functionality and simplicity further stresses the importance of identifying the essential tasks to be performed within the software in order to achieve a balance. The most ideal solution was found to be that Architects delivered their initial proposals in 3-D. The flow, cost- and time efficiency were all thought to be positively influenced by such an initiation.

The software was seen to facilitate the process of visualizing and communicating blueprints of new or renewed offices. The functionality of 3-D, rendering views, inclusion of human models and ability for accuracy were examples of highly appreciated components thought to contribute to the process. This was further believed to increase end-users understanding of the new work environment and save time, due to the highly realistic style of illuminating matters of importance. With SketchUp's high compatibility mode and quality, the CAD-tool was found to help facilitate the communication between Architects and OHS practitioners, as well as result in a better inclusion of OHS practitioners earlier in the process of workspace design projects.

8.1 Recommendations

The few number of respondents involved in the usability sessions stresses the need for further research in order to determine the tools' actual applicability to OHS practitioners and inexperienced users alike. With the results showing such high value for the collaboration with Architects, this further includes involving Architects working on workspace design projects.

Although not a focus in this study, an investigation into Universal Accessibility may be highly valuable in order to cater for the entire population of Ergonomists and Safety-engineers, regardless of age and disabilities. Catering for the novice users of CAD is only part of it.

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10.0 Appendices

Appendix 1: Other Contributors

- CAD/BIM-specialist. Educational background as Structural Engineer. Previous experience collaborating with Architects.
- CAD/BIM-manager for a big Architectural firm. Educational background as Construction Engineer, specialized on CAD-tools. Collaborates with Interior Designers/Architects.
- Researcher at the Division of Ergonomics and Aerosol Technology in the Department of Design Sciences. Previous research conducted on visualization techniques for participative design.
- Newly registered Architect. A few years experience working alongside Architects. No previous experience collaborating with OHS practitioners.
- 3-D Developer Engineer at a City Planning Office. User of SketchUp Pro.
- Professor in Integrated Product Development. Involved in visualization techniques at a big manufacturing firm.
- Associate professor in the department of High-Performance Computing and Visualization. Previous research e.g. Human-Computer Interaction and Information Visualization.

Appendix 2: Interview Guide, Qualitative Interviews of Resp. A and B

1.) Kan du beskriva vilka professioner som oftast arbetar inom företagshälsovården (FHV)?

2.) Kan du beskriva vilka professioner inom FHV som oftast arbetar med kontorslayout?

3.) Vid planering av kontorslayout, vad anser du att FHV gör vad gäller arbetsuppgifter?

4.) Kan du så utförligt som möjligt beskriva vad och hur du anser att FHV gör och agerar efter att de mottar ritningsförslag från arkitekterna, tills dessa förmedlas till företagen?

4.1) Kan du beskriva hur dessa ritningar ser ut, vad de inkluderar, eventuellt exkluderar?

5.) I förhållande till de professioner som du anser arbeta med kontorslayout (inom FHV), vem skulle du tänkt har minst erfarenhet av att använda datoriserade design-verktyg (computer-aided design)?

5.1.) Vilken nivå skulle du tänkt dig att de ligger på?

6.) Tror du att det finns en stor variation i behov (i form av svårighetsgrad) för de olika professioner inom FHV som arbetar med kontorslayout, i.f.t. ett datoriserad ritnings-verktyg?

6.1.) Vilka andra faktorer än du har nämnd tror du att kan spela in?

7.) Vid användning av ett datoriserad ritnings-verktyg, tror du att programmet skulle komma att användas av enskilda individer, eller av ett par eller flera personer samtidigt?

7.1) Förutan de inom företagshälsovården som arbetar med kontorslayout, vem andra skulle kunna påverkas av ett sådant ritnings-program?

8.) Om man hittat ett type datoriserad ritningsverktyg som skulle kunna visualisera kontorslayout i 3D, vad ser du för dig att FHV skulle kunna använda programmet till?

9.) Utifrån din erfarenhet och åsikt, tror du att FHV skulle vara villig att betala för ett sådant program och i så tillfället, hur mycket maximalt (ca) tror du att de skulle vara villiga att betala?

10.) Det finns ett antal olika principer och riktlinjer för att bedöma i vilken grad ett program är användbar. Har du kunskap och åsikt om vad ett datoriserat ritningsprogram skulle behöva uppnå för att vara lämplig/användarvänlig för FHV?

11.) Om det går att generalisera, hur ser omgivningen oftast ut på FHV?

11.1) Vart i omgivningen ser du för dig att ett sådant datoriserat program skulle kunna tillämpas?

11.2) Har du kunskap om vilka operativa (dator) system som oftast används vid FHV? (till exempel Mac OS, Windows, Linux)

11.3) Är det något annat i företagshälsovårdens omgivning som du tror kan påverka samspelet mellan användare och design-verktyget?

Appendix 3: Ratings Sheet Usability Testing

DEL 1) VIKTNING AV KRITERIUM

Skala: 1-5

5= Instämmer helt
4= Instämmer delvis
3= Varken eller
2= Instämmer inte helt
1= Instämmer inte alls

KRITERIUM	**VIKTNING AV BETYDELSE**		**Om du ändrat din viktning efter testet av programvaran, vad är orsaken till denna ändring?**
Uppnåandet av uppgifter Programvaran visar förmåga att uppnå de avsedda uppgifterna.			
Kvaliteten på utfall Slutresultatet når det förväntade utfallet.			
Lärbarheten Kräver lite ansträngning och utbildning för att nå en kompetent nivå av prestanda, t.ex. finns visuella ledtrådar och terminologi som gör gränssnittet begriplig, lättförståelig, lärbart.			
Minnesvärdheten Metoder eller funktioner är enkla att minnas.			
Programvarans hastighet Handlingar och uppgifter kan utföras med hög hastighet.			
Förebyggande av fel Gränssnittet ger feedback, diagnostiserar och möjliggör återhämtning av utförda fel inom en läglig tid och utan allt för stor ansträngning.			

Tillfredsställelse Du upplever tillfredsställelse med funktioner och med utformningen av programvaran, exempelvis de stöd som fås för att utföra de önskade uppgifterna.			
Användarmanualer Användarmanualer i programvaran är enkla att hitta och använda utan att det stör andra funktioner.			
Enkelhet Programvaran har en hög grad av gissbarhet och intuitivitet; exempelvis krävs få handlingar för att utföra uppgifter. Termer är få, välbekanta och konsekventa.			
Återkoppling Informativ återkoppling ges vid utförande av handlingar.			
Språk Du är tillfredsställd med språket i programvaran, exempelvis med de engelska termer som används.			

DEL 2) SKATTNING AV KRITERIUM

Skala: 1-5

5= Instämmer helt
4= Instämmer delvis
3= Varken eller
2= Instämmer inte helt
1= Instämmer inte alls

KRITERIUM	SKATTNING AV PROGRAMVARAN	ARGUMENT
Uppnåandet av uppgifter Programvaran visar förmåga att uppnå de avsedda uppgifter.		
Kvaliteten på utfall Slutresultatet når det förväntade utfallet.		
Lärbarheten Kräver lite ansträngning och utbildning för att nå en kompetent nivå av prestanda, t.ex. finns visuella ledtrådar och terminologi som gör gränssnittet begriplig, lättförståelig, lärbart.		
Minnesvärdheten Metoder eller funktioner är enkla att minnas.		
Programvarans hastighet Handlingar och uppgifter kan utföras med hög hastighet.		
Förebyggande av fel Gränssnittet ger feedback, diagnostiserar och möjliggör återhämtning av utförda fel inom en läglig tid och utan allt för stor ansträngning.		
Tillfredsställelse		

Du upplever tillfredsställelse med funktioner och med utformningen av programvaran, exempelvis de stöd som fås för att utföra de önskade uppgifterna.		
Användarmanualer Användarmanualer i programvaran är enkla att hitta och använda utan att det stör andra funktioner.		
Enkelhet Programvaran har en hög grad av gissbarhet och intuitivitet; exempelvis krävs få handlingar för att utföra uppgifter. Termer är få, välbekanta och konsekventa.		
Återkoppling Informativ återkoppling ges vid utförande av handlingar.		
Språk Du är tillfredsställt med språket i programvaran, exempelvis med de engelska termer som används.		

Om du var en del av ett par-test, vilka av uppgifterna fick du personligen prova på?

Att navigera i användarmanualer ☐

Att bygga upp en modell av ett hus ☐

Att testa dig fram i en redan uppbyggd modell ☐

Att visualisera en kontorslayout ☐

Appendix 4: Subsequent Interview: Usability Testing

Kostnad:

1) SketchUp Pro kostar för närvarande 590 USD/ca.4900 SEK. Utifrån det du nu känner till av SketchUp Pro, tror du att denna kostnad är acceptabel för företagshälsovården att bekosta med tanke på dens karakteristik och funktion?

Uppgift

2) Utifrån de tre uppgifterna att bygga, manipulera och visualisera, var det någon uppgift du tyckte var svårare än de andra?

2.1) Kan du förklara värför?

Tidsaspekt:

3) Hur lång tid tror du att det vill kunna ta för dig att lära dig använda ett sådant program för det ändamål som beskrivits?

Förbättringspotential:

4) Om du menar att följande ritningsverktyg skulle behöva förbättras för ändamålet att bygga, manipulera och visualisera kontorslayout i 3D, skulle du föredra ett ritverktyg som var..

1) Lättare (men troligen med mindre funktionalitet) ?

2) Med mer funktionalitet (men troligen svårare/mer avancerad) ?

Användning av ritningsprogrammen i yrkessammanhang:

5) Tror du att SketchUp Pro skulle kunna underlätta processen av att visualisera och kommunicera ritningar av nya/förnyade kontor?

5.1) I så tillfälle, på vilket sätt? *(Eller varför inte?)*

Din bakgrund

1) Vad är din erfarenhet med IT/datorer generellt, inklusive CAD?

2) Har du någon utbildning inom IT/datorer, inklusive CAD?

3) Din professionella titel inom företagshälsovården:

4) Extern eller intern företagshälsovård eller annat?

5) Vad är din erfarenhet med att jobba med layout?

6) Din utbildningsbakgrund:

7) Din ålder (cirkulera åldersintervallen som gäller dig) :

16-34 år **35-49 år** **50-64 år**