To My Husband Süha

# A COMPUTER ASSISTED UNIVERSAL DESIGN (CAUD) PLUG-IN TOOL FOR ARCHITECTURAL DESIGN PROCESS

A THESIS SUBMITTED TO
THE INSTITUTE OF ECONOMICS AND SOCIAL SCIENCES
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IN ART, DESIGN AND ARCHITECTURE

By

Yasemin Afacan
September, 2008

I certify that I have read this thesis and that in my opinion it is fully adequate in scope and in quality, as a thesis for the degree of Doctor of Philosophy in Art, Design and Architecture.

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# ABSTRACT

## A COMPUTER ASSISTED UNIVERSAL DESIGN (CAUD) PLUG-IN TOOL FOR ARCHITECTURAL DESIGN PROCESS

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Managing universal design process is a highly complex and challenging design task due to its multi-parameter characteristics. It becomes even more difficult while accommodating the needs of people with diverse impairments in architectural design process. Thus, this study aims to propose the development and implementation of an innovative computer-assisted universal design plug-in tool (CAUD) in the initial design phase that is compatible with the existing three-dimensional design software, SketchUp. Based on the theories and researches, the cognitive design strategies are analyzed for the efficiency of the knowledge support of the CAUD plug-in tool. Thus, the capabilities of the plug-in tool are defined according to the accommodation with an ideal cognitive strategy during analysis, synthesis and evaluation operations. Moreover, to achieve challenges of selecting the right set of universal design requirements within the plug-in tool, a prioritization technique that is based on the hybridization of the two techniques, the Planning Game (PG) and Analytic Hierarchy Process (AHP) using a cost-value approach is proposed. Through the proposed hybrid technique, requirement–design relationships are computed and the cost-value ratios of requirement priorities are represented. The study that is developed for universal kitchen design applications yielded a significant contribution to the universal design problem-solving process in a computer-aided design (CAD) environment. Finally, the results of the acceptability studies also showed that the CAUD plug-in tool is found in general useful, understandable, efficient, helpful and satisfactory.

**Keywords:** Universal design, Kitchen design, Architectural design process, Computer- aided design, Cognitive design strategies.

# ÖZET

## MİMARİ TASARIM SÜRECİ İÇİN BİLGİSAYAR DESTEKLİ EVRENSEL TASARIM EKLENTİ ARACI

Yasemin Afacan
Güzel Sanatlar, Tasarım, ve Mimarlık Fakültesi
Doktora Çalışması
Tez Yöneticisi: Doç. Dr. Halime Demirkan
Eylül, 2008

Evrensel tasarım yönetimi, çok parametreli olma özelliğinden dolayı son derece karmaşık ve zor bir tasarım konusudur. Mimari tasarım sürecinde çeşitli özürleri olan insanların tasarım gereksinimlerini karşılarken daha da zorlaşmaktadır. Bu çalışma, SketchUp adlı üç boyutlu tasarım yazılımı ile uyumlu çalışabilen bir bilgisayar destekli evrensel tasarım eklenti aracının gelişimini ve uygulamasını önerisini kapsamaktadır. Bu eklenti aracının bilgi desteğinin verimli olabilmesi için, kuram ve araştırmalar çerçevesinde bilişsel tasarım stratejileri araştırılmıştır. En uygun bilişsel tasarım stratejisine göre bu aracın analiz, sentez ve değerlendirme işlemleri sırasındaki yetenekleri bu şekilde tanımlanmıştır. Ayrıca, iki önceliklendirme tekniğinin (oyun planlama ve maliyet değer yaklaşım kullanan analitik hiyerarşi süreci) hibritleşmesine dayalı bir önceliklendirme tekniği önerilmiş ve önerilen bu teknik ile doğru evrensel tasarım gerekliliklerini seçebilme zorluklarının üstesinden gelinmiştir. Önerilen hibrit tekniği ile gereklilik-tasarım ilişkileri hesaplanmış ve maliyet-değer oranları bulunmuştur. Evrensel mutfak tasarım uygulamaları için geliştirilen bu çalışma, bilgisayar destekli tasarım ortamındaki evrensel tasarım problemini çözme sürecine önemli katkılar sağlamıştır. Son olarak, kabul edilebilirlik çalışmaları sonuçları bu eklenti aracının kullanılabilir, anlaşılır, verimli, yararlı ve memnun edici olduğunu göstermiştir.

**Anahtar Sözcükler:** Evrensel tasarım, Mutfak tasarımı, Mimari tasarım süreci, Bilgisayar destekli tasarım, Bilişsel tasarım stratejileri.

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# 1. INTRODUCTION

In the last decades, there was a growth in the number of elderly population and disabled people. World Health Organization (WHO) "estimates suggest that the world total will be more than 1 billion aged 60 or over by the year 2025" (Marshall et al., 2004, p.1203). Furthermore, the needs and demands of diverse population members, who are children, pregnant, adult or disabled, vary considerably. Therefore, today there is a growing awareness of universal design among the designers in order to satisfy the needs of the diversified users in many countries around the world. Universal design aims to design spaces and products for the vast majority of the world that can be used without any adaptation or stigmatizing the user. Therefore, it emphasizes inclusivity in the design process regardless of the age, ability or size of users (Ostroff, 2001). The seven principles of universal design guide the designers and consumers by emphasizing the characteristics of more usable products and environments while providing a framework for the systematic evaluation of new or existing designs (Story, 2001). Further, Iwarsson and Stahl (2003) added that "application of the universal design principles highlights that universal design requires integration of accessibility and usability features from the onset, removing any stigma and resulting in social inclusion of the broadest diversity of users" (p. 61).

However, designing products, built environments or urban spaces that have different functions and can be used by all people with diversified abilities is a challenging task. The difficulty lies in the prioritization of the diverse users' requirements while regarding the type of disability or functional limitation of users. Therefore, this study considers universal design as a process that is composed of a series of design decisions, and each has different parameter values, design constraints and requirements. There is no unique universal design parameter that can be optimized (Guimaraes, 2001). Rather, there are sets of parameter conditions that designers should take into account in the conceptual design phase.

Due to its multi-parameter characteristics, universal design process is a difficult one to manage. Since computers are the best and powerful tools in problem solving during complex design processes, this study aims to develop a computer-aided design (CAD) tool to assist designers in universal design process. In the last 30 years, there had been attempts to assist designers computationally while performing more demanding design tasks (Carrara and Kalay 1994; Chastain et al., 2002; Kalay 2006; Sequin and Kalay 1998). Since most designers now use CAD tools extensively, it is highly appropriate to provide support for universal design through this medium. In this respect, it is crucial to explore a computer assisted universal design (CAUD) process for enhancing universal design implementations. In this introductory part, a detailed problem statement, and the aim and scope of the study are given.

## 1.1 Problem Statement

In recent years, there were several applications of universal design in various fields such as interior and product design, design education, house and landscape design. (Mueller 1997). However, universal design is still in its infancy, and managing universal design process is a highly complex and challenging design task. It becomes even a more difficult process while accommodating the needs of people with diverse impairments (visual, hearing, physical, cognitive and language) in the conceptual phase of a design process. In this respect, this study addresses the universal design concept in a computer medium during the conceptual design phase. Such a CAD assistance will guide designers while designing the products and built environments without physical, social and attitudinal barriers and making everyday life of the users much easier in the ever-changing global environment.

## 1.2 Aim and Scope

The demand for universal design is an essential concern in all products and environments. However, due to its complexity, designers struggle with the universal design requirements either in their academic or professional life. Therefore, the study aims to propose the development and implementation of an innovative universal design plug-in tool in the conceptual design phase that is compatible with the existing three-dimensional design softwares. Especially in the conceptual design phase, where various design ideas need to be searched and quickly evaluated, the use of a CAUD plug-in tool can be very effective to deal with the conception of universal design ideas. In this respect, the main goal of this study is to explore how universal design approach can be computationally aided in the conceptual design phase. Moreover, it is also essential to answer the questions of ‘what are the universal design requirements to be considered in the conceptual design phase?’, ‘what are the importance degrees of each requirement?’ and how can they be integrated with the computational design tools to support the universally designed products or environments?’ Thus, in this study the proposed CAUD plug-in tool provides support for two critical aspects of design process. The first aspect is the provision of project specific and prioritized universal design requirements so that designers can easily cope with universal design data consistent with their cognitive problem-solving activities. The second one is the support of an efficient and effective computational medium while using these prioritized requirements in the conceptual design phase.

## 1.3 Structure of the Thesis

The chapters of the thesis are organized as follows. In Chapter 2, in which the theoretical framework the study is formed, first the related studies that are examined on the topics of development of CAD systems, their potentials and the requirements of conceptual design phase in utilizing CAD systems are investigated. Then, the cognitive design strategies are dwelled upon to find a suitable design strategy for the efficiency of the knowledge support for the CAUD plug-in tool. Moreover, cognitive needs of designers for universal design problem-solving are analyzed with respect to three design operations: analysis, synthesis and evaluation. Chapter 2 also deals with the structural model of the CAUD plug-in tool based on Eastman's (1999) typical structure for a modern CAD system is introduced and its three main environments; modeling, application language and universal design, are explained in relation to SkecthUp software.

In the third chapter, which is on the capabilities of the CAUD plug-in tool, the information flow process of the plug-in tool is explained with respect to how it addresses the suitable cognitive strategy of universal design process. Moreover, the design knowledge support scheme of the plug-in tool for analysis, synthesis and evaluation operations is illustrated including the interface designs required for each operation. In Chapter 4, the more elaborated prioritization techniques in literature are examined as a means for systematic specification and prioritization of the universal design requirements for the CAUD plug-in tool interface. To achieve the challenges of the universal design problem-solving, a prioritization technique that is based on the hybridization of the two techniques, the Planning Game (PG) and Analytic Hierarchy Process (AHP) using a cost-value approach, is suggested and its overall structure introduced. In the following chapter (Chapter 5), the CAUD plug-in tool is developed and implemented for a universal kitchen design in three stages: Stage I- elicitation of the diverse user needs; Stage II- application of the prioritization techniques and Stage

III- incorporation of the derived priorities into the CAUD plug-in tool. The detailed information on each stage including the relevant steps is given.

In Chapter 6, the assessment of the user acceptance of the CAUD plug-in tool is conducted through the System Acceptance Questionnaire (SAQ). This chapter includes also statistical analysis of the acceptability scores including the respondents' opinions about the CAUD plug-in tool. Moreover, guidelines for future researches on CAD tools are presented. In the final conclusion chapter, the purpose and results of the development and implementation of the CAUD plug-in tool are summarized. Contributions of the study to the related literature are discussed to constitute a basis for further studies. This chapter is followed by a list of the references and the appendices.

## 2. THEORETICAL FRAMEWORK OF THE STUDY

Reviewing the literature related to universal design shows that the universal design philosophy has been studied from various points of view. Designers dealt with the universal design applications in the industrial/architectural/urban design practice (Danford and Tauke, 2001; Ikeda and Takayanagi, 2001; Mueller, 2003; Story et al., 1998). They were also interested in the participation of diverse user groups in the universal design process (Demirbilek and Demirkan, 2004); development of universal design evaluation models in the built environments (Preiser, 2001; 2003); integration of universal design principles into the design education (Jones, 2001; Ostroff, 2003; Tepfer, 2001); implementations of the universal design principles in the consumer products industry and automotive marketing (Beecher and Paquet, 2005); and development of universal design solutions within the context of assistive or smart home technology (Dewsbury et al., 2003; Tobias, 2003).

Despite the extensive literature and case examples on universal design, there is a little research on how universal design can be computationally supported; and how computers can assist the designers throughout the universal design process. A limited amount of work has attempted to provide the use of computer-based universal design tools in supporting the development of universal products and environments. Among these attempts, HADRIAN (Human Anthropometric Data Requirements Investigation and ANalysis) was a prototype CAD tool for 'design for all' that worked together with an existing human modeling software system called SAMMIE (System for Aiding Man Machine Interaction Evaluation) (Marshall et al., 2004; Porter et al., 2004). It provided a simplified method for performing ergonomics evaluations of a sample set of individuals in a CAD environment. Another design attempt was HUDCAD (Housing and Urban Development Computer-Aided Design), which aimed to achieve affordable housing services for the vast majority of people and integrates geometric modeling, design analysis, drawing/drafting, data management/storage and transfer into one CAD system (Chakrabarty, 2007).

Although both HADRIAN and HUDCAD were developed as computer-aided design analysis tools to achieve efficient, effective and satisfied designs, they were in the sense of usability attempts rather than universal design tools in a wider scope. Universal design approach is mainly different from the traditional usability attempts and ergonomics evaluations by considering design for everyone rather than the vast majority of a target population (Beecher and Paquet, 2005). Examining universal design issues revealed that to date, universal design has been studied mainly as an extension of physical accessibility codes, usability issues and ergonomics perspective. Accessibility codes focused on the functional issues and minimal solutions, whereas universal design expands these codes by addressing a broad range of people with diverse ages, abilities and sizes (Levine, 2006). While considerations of accessibility, usability and ergonomic issues are necessary for universal design, they are not sufficient to generate promising universal design alternatives and then, refining them to a satisfactory design solution. “Universal design extends the benefits of good functional design to many groups of people who are not necessarily classified as having disability or aged, but who routinely encounter functional obstacles in their daily lives”( Levine, 2006, p.9). Therefore, it is essential for a CAUD plug-in tool to manage the extent of variations in the physical characteristics and capabilities of each individual, in every design aspect of daily life ranging from product design to urban planning. Also, the compatibility of this plug-in tool with the conventional computational mediums is important, so that every designer can be encouraged to utilize this computer support during the universal design process. In this respect, this study will contribute to the literature by introducing the first CAUD plug-in tool that provides a support for designers to manage universal design requirements in the conceptual design phase. At this point, it is essential to review the background of CAD systems and their current state in design practice to understand the potentials of CAD environments for a universal design process.

## 2.1 Development of CAD Systems

The first developments of CAD begun in the mid-1950s to calculate the engineering formulas automatically (Eastman, 1999). Later in 1963, the first interactive computer graphics was developed with the significant pioneering effort of Ivan Sutherland’s

Ph.D. thesis ‘Sketchpad: A Man-machine graphical communication system’ (Mitchell, 1977; Sutherland, 1963). Sutherland’s thesis was the precursor of today’s CAD/CAM (Computer-aided manufacturing) /CAE (Computer-aided engineering). Later, the interest of computer-aided architectural design has rapidly grown with the search for a systematic method of design and with the publication of Alexander’s book entitled *Notes on the Synthesis of Form* (Carrara and Kalay 1994). In the mid-1970s, the applications of CAD techniques became apparent in architecture and in many other fields by the emergence of a number of technical journals (Mitchell, 1977). Three-dimensional (3D) wire-frame drawings were introduced with the new editing options for surface and solid modeling operations (Eastman, 1999). In the late 1970s, the first commercially available object-oriented (OO) languages were introduced. OO languages suggested seeing software objects as physical objects to write programs in the same way real objects interact (Eastman, 1999).

In 1990s, design in a CAD environment became a social and collaborative activity with the more sophisticated CAD tools and networking technology such as the Internet (Jeng and Eastman, 1998; Mitchell, 1994). Various electronic information media were developed for spreading/sharing/exchanging design knowledge and information such as: High-level system environments supporting complex, open and evolvable systems; organizational learning environments; domain oriented environments, World Wide Web (WWW) and interactive environments (Fischer, 1993).

Eastman (1999) examined this 40 years history of CAD technologies. His timeline chart is beneficial in terms of comprehending the major technological developments affecting CAD systems (Figure 2.1). Figure 2.1 also illustrates the time relationships between the display technology developments and software technology developments in detail.

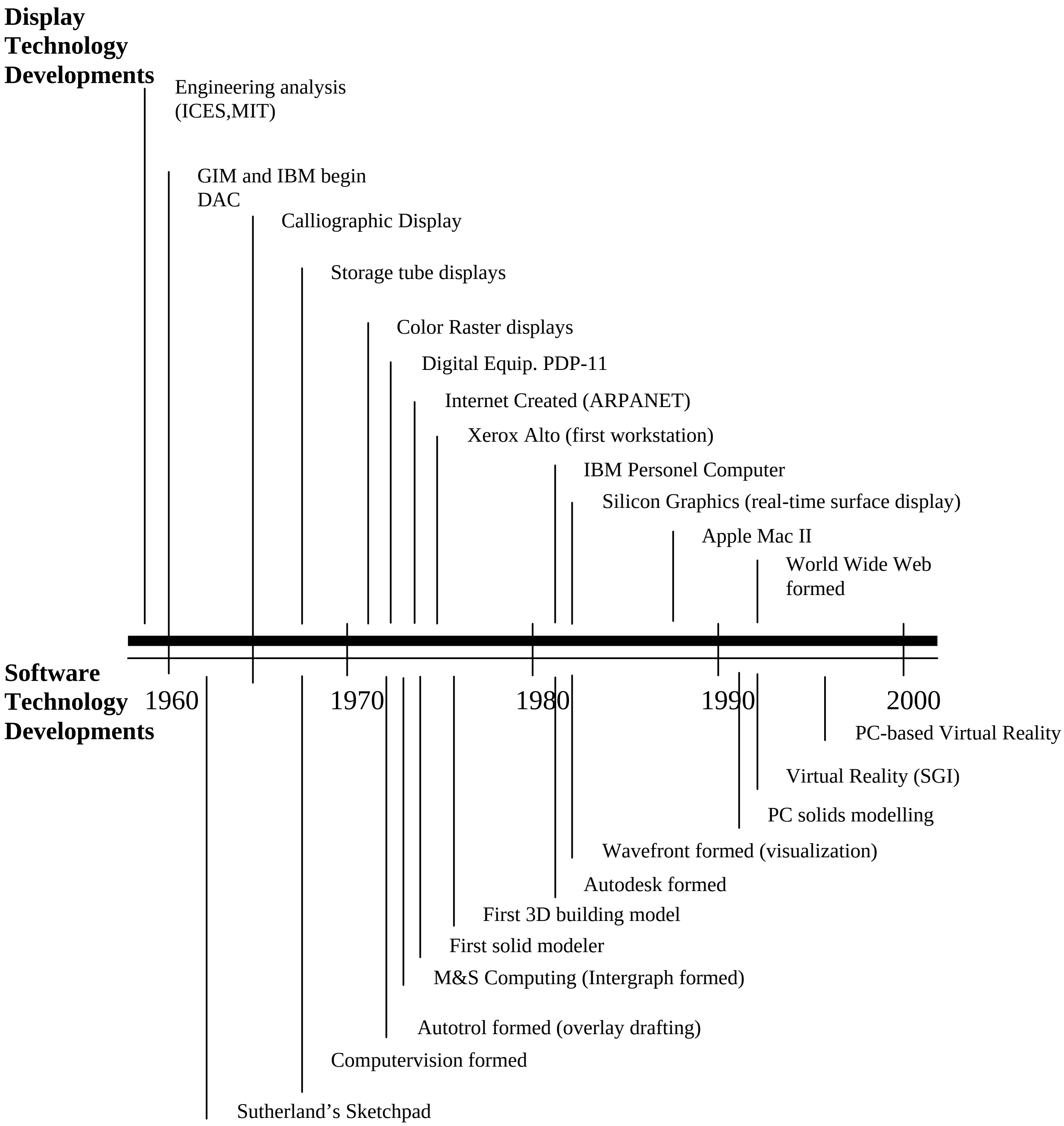


Figure 2.1. A timeline of major technological developments affecting computer-aided design (Eastman, 1999, p.38).

Lawson (1998) also explored the history of CAD systems and classified the role of computers in design process under five categories: computer as a designer, computer as a drawing tool, computer as a modeling tool; computer as an evaluative tool and finally as a design assistant. Computer as a designer can produce a solution to the design problem that is formulated and presented by the human designer (Kalay, 2006). Computer as a drawing tool provides the easy use of graphical elements such as compose, edit and transform that are difficult in manual drawing systems (Lawson, 1998). Computer as a modeling tool allows designers to construct three-dimensional design projects from their two-dimensional drawings. Computer as an evaluative tool evaluates the design and validates its correctness by receiving all relevant data from the created project, mapping these data into separate data structures and sending the modified data back to the project (Kim et al., 1997). Computer as a design assistant is capable of checking design according to the series of criteria and redoing of design (Lawson, 1998).

Recently, a new generation of geometric modeling tools has been developed regarding the computer's role in design process. These new systems such as AutoDesk Revit, Graphisoft ArchiCAD, Bentley Triforma are based on parametric modeling and hold the potential of providing designers with easy designing, drawing, modeling, rendering and editing capabilities (Eastman, 1999; Hernandez, 2006; Sacks et al., 2004). Origins of the parametric modeling go back to the Sutherland's 1963 Ph.D. thesis 'Sketchpad', and it is evolved slowly with the development of the CAD systems (Eastman, 1999). Lee et al. (2006) described parametric modeling as an effective, efficient and flexible Building Information Modeling (BIM) system, in which building information was managed; defined in interoperable and reusable way; and supported by a set of parameter operations. Unlike traditional CAD systems, such as AutoCAD, in the parametric modeling building objects like walls, windows, doors contain rich embedded information. These objects can be parametrically modified with the changes or additions occurring at the new parametric relations depending on the designers' intent (Lee et al., 2006; Sacks et al., 2004).

As a result of these technological advances in CAD industry, many CAD systems were developed. Each CAD system, which is complex and written by a programming language, has a typical structure. Eastman (1999) described the typical structure of a modern CAD system as seen in Figure 2.2. This typical structure is composed of software modules that are shown by the boxes. The 'window manager' is the user interface that receives all of user input and transfers it on the 'command processor'. The 'command processor' analyzes the actions of the mouse or keyboard and translates them into the 'graphic operators' with the identified parameters that manipulate graphical primitives such as line, curves, text etc. and the display list in relation to 'the drawing database' and 'symbol library' of the CAD system (Eastman, 1999). The 'interaction utilities' are the tools which provide information to the user as the real-time coordinates of the interactions and are not directly related to the project database (Eastman, 1999). The 'application language' and 'application code' are the components of the required programming language. ‘IGES’ (Initial Graphics Exchange Specification) and the ‘report generator’ store information about the previously conducted projects (Eastman, 1999).

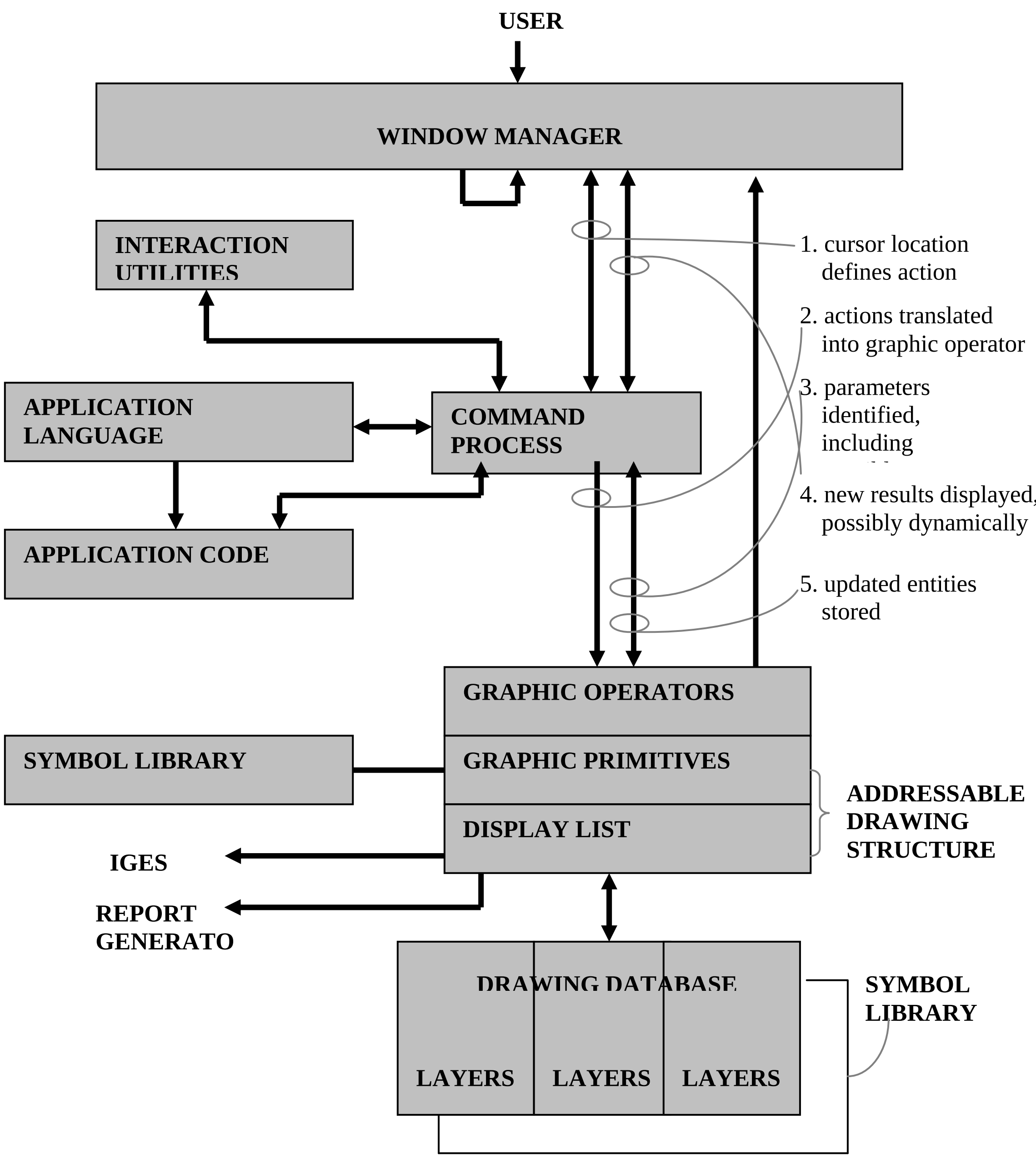


Figure 2.2. The typical structure of a modern CAD system (Eastman, 1999, p.41).

Today, looking back to the 50 years of the CAD systems' history it is essential to state that the introduction of the CAD tools in architecture practice has replaced the traditional design medium. They made use of computer indispensable by providing new affordances; more intelligent, efficient and coordinated design and construction processes, and new representation innovations (Chastain et al., 2002; Kalay, 2006). Yet, there are many debates on the unsuitability of computer usage in the conceptual phase of design process (Chastain et al., 2002; Kalay, 2006; Lawson, 1998; Meniru et al., 2003; Ye et al., 2006; Zheng et al., 2001). In order to discuss this issue broadly and to provide a better link between CAD potentials and the requirements of conceptual design phase, the next part delves deeper in the utilization of CAD systems in the conceptual phase of design process.

### 2.2 CAD Systems in the Conceptual Design Phase

Conceptual phase is the initial phase of a design process in which the designer is engaged in a series of design activities (Akin, 1986). Reviewing the design literature, it is seen that there are various approaches to the analysis of the design activities in the conceptual design phase.  Newell and Simon (1972) defined these activities as the thinking acts of problem-solving process. They analyzed the designer's thinking process from the point of problem structuring and representation of the design problem while reducing the problem into manageable proportions (Newell and Simon, 1972; Simon, 1979). Akin (1986) elaborated Newell and Simon's problem-solving process by analysing the cognitive mechanisms in design problem solving where he classified the design process in three conceptual design activities as searching, representing and reasoning. Schon’s (1983) great contribution had been to bring the notion of ‘reflection-in-action’ into the conceptual design activities in which designers not only produce alternative solutions to the design problem but also created a language by their sketches. Coyne et al. (1990) approached to the conceptual design activity as a knowledge-based activity in which design problems were solved by applying automated reasoning procedures combined with the facts and rules of knowledge bases.

Although the conceptual phase of design with its above explained design activities is potentially the most vigorous, dynamic, informal, complex and creative phase of the overall design process, it is the least understood and least supported by the CAD systems (Hendricx and Neuckermans, 2001; Zheng et al., 2001). Since the technological developments affecting CAD systems and most of the commercial CAD manufacturers have mainly dealt with the geometric manipulations of designs rather than their conceptual aspects (Tay and Gu, 2002), the conceptual phase of design process is elusive for many CAD software producers. Therefore, there is a need to develop a CAD environment that supports the required design activities of the conceptual phase.

Beginning from 1990s a number of design attempts have been developed for the efficient and effective CAD use in the conceptual design phase such as a CAD environment supporting the knowledge-based design decision support (KNODES) by Rutherford and Maver (1994), a software environment to support early phases in building design (SEED) by Flemming (1994) and a CAD system for a knowledge-based computational support for architectural design (KAAD) by Carrara et al. (1994). Moreover, there are other design contributions of three-dimensional virtual modeling and collaborative environments to the conceptual design phase such as the virtual design tool named Sculptor (Engeli and Kurmann, 1996), a suite of prototype CAD tool based on a very large scale integrated circuits (VLSI) domain (Sequin and Kalay, 1998) , the development of a multi-agent design system (Demirkan, 2005), and the innovative conceptual design system by Loughborough University (LUCID) (Ye et al., 2006). Among these attempts, there is a consensus on the issue that an efficient and effective CAD system should assist designers from the beginning of a design process, and the conventional CAD systems do not provide suitable medium for assisting the conceptual phase of design process.

Kalay (2006) used two paradigms to explain the current relationship between CAD tools and conceptual phase of design. The first paradigm is ‘forcing square peg into a round hole’. With this paradigm he implied that design has suffered from the computing technologies. Since the conceptual phase of design process includes unstructured forms of pictorial representations such as bubble diagrams, abstract diagrams, functional diagrams or sketch plans, together with less abstract and more realistic visual perspectives (Gero and Purcell, 1998), the conventional CAD tools are lacking this required ambiguity and flexibility. The over preciseness cause to mislead the designers in the conceptual design phase. The second paradigm is ‘horseless carriage’ paradigm. With this paradigm Kalay (2006) meant that the computing technology had changed the perception of design practice. He also added that precision, affordances and technical characteristics offered by CAD tools such as AutoCAD affected designers’ reasoning. Some of the solid modeling tools afford well defined geometries, objects and dimensions so that designers’ choices are limited with those available libraries. Chastain et al. (2002) claimed that they restricted designers’ creative ways of approaching to design. Thus, the computational technology has replaced the human hand and produced a number of exact geometries rather than a series of imprecise sketches and schematic drawings.

At this point, the comparison of the designers’ cognitive actions in conventional versus digital media during the conceptual design phase becomes important. Bilda (2001) made this comparison and concluded that CAD’s convenience for the conceptual design phase depended on designers’ designing habits and the inflexibility of the CAD software. Lok (2004) examined the software packages used by interior designers and investigated the extent to which CAD tools replaced the human hand in the generation of early design concepts. She concluded that designers mostly prefer the more intuitive CAD tools, which resemble very much the way that they sketch.

Therefore, recently many digital sketching tools have been developed which aims to make representations for conceiving and communicating in the conceptual design phase. Juchmes et al. (2005) classified these sketching tools based on their compatibility with the current practice under four categories: (1) Drawing tools containing traditional bitmap drawing applications; (2) Natural communication tools using free-hand sketch as a quick way to create graphs and diagrams; (3) Sketch-based retrieval tools using free-hand sketch as a quick way to retrieve graphical information, and (4) 3D modeling tools for the projective and perspective sketches. Since sketch is the first part of the design process for the expression and manipulation of rough ideas, it is important to use the appropriate CAD tool. Otherwise, any inappropriate use can result in a poorer practice and misleading design solutions.

Based on the previous researches, this study proposes the development and implementation of the universal design plug-in tool for the conceptual design phase. Among the various phases of design process (i.e. conceptual, design, implementation phases), conceptual phase is the least understood phase, therefore, it is the least supported one by the computational tools. Besides, this study is concentrated on the conceptual design phase for providing universal design support based on the following two facts: The first fact is, the majority of universal design data should be managed within a short time in this phase; and the second is, universal design decisions made in this phase have a large impact (nearly 80%) on the overall design success and cost (Baya and Leifer, 1996).

Moreover, to be consistent with the 'designerly ways of knowing' (Cross, 2006) is the central issue both for the success of the conceptual design phase and development of a CAD support system. In this respect, it is required to analyze the strategic approach of the designer to the problems while exploring his cognitive needs in the conceptual design phase (Cross, 1989; Cross et al., 1996; Kruger and Cross; 2006; Restrepo and Christiaans; 2003; Roozenburg and Eekels, 1994). Thus, the next sections of the study deal with finding a suitable design strategy for the efficiency of the knowledge support for the CAUD plug-in tool. The following parts of the study are important in terms of formulating the capabilities of the plug-in tool.

## 2.3 Cognitive Strategies of Designers in the Conceptual Design Phase

Designers should operate an effective cognitive strategy in order to increase the possibility of creating promising concepts and satisfactory solutions in the conceptual designs as early as possible (Chakrabarti and Bligh, 1996). Since the major aim of the conceptual design activities is to analyze the objectives, generate a wide range of solution alternatives and to evaluate/select the most satisfactory solution within a short time (Liu et al., 2003). It is highly important to identify the most suitable cognitive strategy for the designers in order to successfully achieve all these activities within a CAUD environment. If the strategic approach of the designer is not an appropriate one, then the better or best alternatives can be overlooked. Therefore, the following two sections define the cognitive design strategy and review the categories of cognitive strategies in the design literature to identify the suitable strategy for the CAUD process.

### 2.3.1 What Is a Cognitive Design Strategy?

Over the last three decades, design research in cognitive psychology and design thinking has largely concentrated on the designers' interaction with the design process and their engagement with the design problem regarding a sequence of strategies (Akin, 1986; Cross, 1989; Cross et al., 1996; Lawson, 1979; 1990; Schon, 1983; Simon, 1979). Having a strategy is important in terms of being aware of how one is intended to find the solution. In this respect, Cross (1989) defined the design strategy as the general plan of a sequence of particular actions employed by the designer throughout the design process. Roozenburg and Eekels (1994) described the strategy as the designer's approach to realize the goals of the design problem. Gero and Neill (1998) expanded Roozenburg and Eekels' (1994) definition by viewing designer's approach either in terms of a short or long term plan. They identified two types of design strategies; micro strategies related with the current state of the design process and macro strategies related with the whole design process. Ho (2001) related these micro and macro strategies to the systematical structuring of design problems and described the design strategy as the designer's way of decomposing design problems at different stages of the design process. Restrepo and Christiaans (2003) also emphasized the role of problem structuring in approaching both to the objectives of the problem and the desired aspects of the solution alternatives.

Reviewing the above definitions shows that the design strategy is often defined as the way in which a design problem is tackled. However, its employment differs from one designer to the other since problem solving in design is based on the subjective interpretations of the designer (Cross, 1989; Demirkan, 1998; Schon, 1983). Moreover, Restrepo and Christiaans (2003) stated that research on software design, design engineering, industrial design and architectural design implied that a strategy is also not discipline-specific. Therefore, it is not possible to systematize the design strategies according to the different disciplines. Then, the question of what is the proper systematic approach to categorize the design strategies arises. The next section tries to find an answer to this question in detail.

### 2.3.2 Categorization of Cognitive Design Strategies

The answer of the categorization of design strategies lies in the studies of Cross (1989) that characterized the overall design process. According to Cross (1989), design process can be considered as a convergent act that is composed of divergent steps (Figure 2.3). The convergent act is concerned with selecting the most appropriate and feasible solution from the alternatives regarding the objectives of the design problem whereas the divergent design approach deals with producing a wide range of design alternatives (Cross, 1989; Dorst and Cross, 2001; Liu et al., 2003). In this respect, it is possible to relate the convergent approach with the problem driven strategies, in which the emphasis lies in defining the problem and finding a solution as soon as possible (Cross 1989; Dorst and Cross, 2001; Kruger and Cross, 2006). On the other hand, the divergent approach is closely linked to the solution driven strategies, in which the designer focuses on generating solutions and gathering information for further development of these solutions (Cross 1989; Dorst and Cross, 2001; Kruger and Cross, 2006). In the study the rationale for the categorization of design strategies is based on Liu et al.'s (2003) divergence/convergence scheme which is stated as the ideal strategic approach to the conceptual design phase. Then, the categorization of cognitive design strategies is as follows; divergence based, convergence based and multiple divergence-convergence based design strategies.

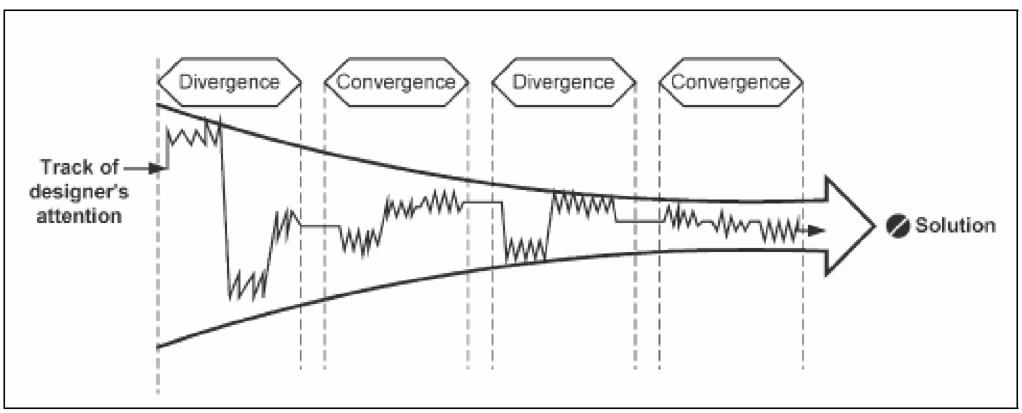


Figure 2.3. The overall design process characterized by Cross (1989, p.145).

#### 2.3.2.1 Divergence Based Design Strategies

The first definition of the divergence based design strategy can be traced back to Lawson's (1979) formalization of solution-focused strategies. Lawson (1979; 1990) explained the divergent thinking process as designer's tendency to suggest a variety of possible solutions until a satisfactory solution is generated. Later, Akin (1986) described designers as divergent thinkers, who seem to find their way in the vast sea of design facts and associations. Cross (1989) defined the divergent approach as a 'random search' strategy, which can be appropriate if the designer has no apparent plan of action and thus, makes the widest search for a possible solution. "Divergent thinkers are good at concept design and at the generation of a wide range of alternatives" (Cross, 1989, p.144). Dorst and Dijkhuis (1996) compared Simon's (1979) rational problem-solving paradigm with Schon's (1983) reflection-in-action paradigm to describe the essential design activity and its related strategy in the conceptual design phase. They related reflection-in-action paradigm to the divergent approach by stating that "describing design as a process of reflection-in-action works particularly well in the conceptual stage of the design process, where the designer has no standard strategies to follow and trying out problem-solution structures" (Dorst and Dijkhuis, 1996, p.269). Ho (2001) described the divergent strategy as a relationship between the expertise and problem-decomposing approach. Comparing the experts with novice designers, Ho (2001) stated that the novice designers deal more with generating alternatives rather than approaching directly to the goal state of the problem that needs structuring at the beginning for a satisfactory solution.

Recently, Liu et al. (2003) approached the concept of divergence from the number of levels of solution abstraction; one level or multiple levels (Figure 2.4). Designers consider the design process as a number of design operations that are difficult to solve simultaneously. Liu et al. (2003) referred to the process of narrowing down the solutions during these operations as the different levels of solution abstraction. In this respect, Liu et al. (2003) described the multiple levels of solution abstraction as decomposing the requirements and tackling with a few of them at a time to reduce their complexity. The divergence based design strategy either with one level or multiple levels is expected to produce a high overall solution quality. However, Kruger and Cross (2006) examined data from protocol studies of nine industrial designers and concluded that designers, who employed the divergence based design strategy produced a low overall solution quality.

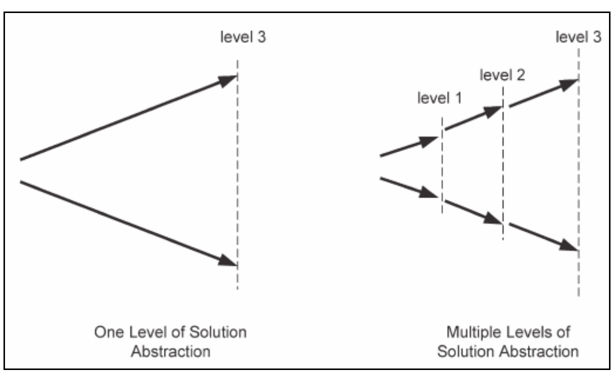


Figure 2.4. Levels of solution abstractions (Liu et al., 2003, p.345).

#### 2.3.2.2 Convergence Based Design Strategies

As well as the divergence based design strategy, the first definition of the convergence based design strategy was made by Lawson (1979; 1990). He described the convergent design thinking with the problem-focused strategy, where the problem is systematically explored in order to generate the correct or optimum solution. Cross (1989) defined the convergent approach as a prefabricated strategy. He described it as follows; “at the opposite extreme to ‘random search’ would be a completely predictable or ‘prefabricated’ which is composed of a completely predictable or ‘prefabricated’ sequence of well-tried and tested actions” (p.144). According to Cross (1989), convergent thinkers are successful in selecting the feasible solution among the alternatives and in satisfying the requirements of the detailing and evaluation phase of the design process. Rosenman and Gero (1994) examined the convergent approach in the architectural design process by defining design as a goal directed activity composed of a prefabricated sequence of analysis, synthesis and evaluation. Dorst and Dijkhuis (1996) related Simon’s (1979) rational problem solving process to the convergence based design strategy. They proposed to use a convergent approach if the design problems were clear-cut, and the designer had a predictable order of a sequence of solving actions in her/his mind. However, the “activities in design do not take place in a predictable order, [and] the information dealt with in design activities cannot be foreseen” (Van Leeuwen and Vries, 2000, p.25). Thus, it is not possible to use solely the convergence based design strategy in the design process. The design strategy should support both the dynamic nature of the design process and the requirements of the designer to generate a satisfactory design solution. In this respect, Liu et al. (2003) proposed the multiple divergence-convergence design strategy as an ideal approach for the concept generation. This third category of the design strategy plays an important role in understanding designers' cognitive needs in universal design process as well as systematizing the universal design problem-solving requirements for the CAUD plug-in tool.

#### 2.3.2.3 Multiple Divergence-Convergence Based Design Strategies

Liu et al. (2003) defined the divergence-convergence based design strategy as "a series of generation and evaluation rather than a single step of generation and evaluation" (p.355). Figure 2.5 illustrates this definition in a more comprehensive way. Carrying out multiple divergent and convergent activities at each level of solution abstraction allows designer to generate a reasonable number of concepts that are manageable at each level of solution domain. Especially this strategy is helpful while the designer uses CAD tools, where "the number of concepts can be considerably larger than the number that s/he can manually generate" (Liu et al., 2003, p.348). Since divergent approaches increase the number of solutions at each solution level from abstract to detailed, they cause to increase the total number of solutions at the end of the design process. However, the solutions can be grouped with the help of the divergent-convergent steps at each level, and other solutions that fail to meet the major objectives are discarded or deleted. Moreover, the designer can also successfully continue to the next solution level with a manageable number of alternatives. Thus, this study defines the multiple divergence-convergence based design strategy as the suitable approach for universal design problem-solving in the conceptual design phase. This strategy is re-mentioned in detail while describing the capabilities of the CAUD plug-in tool and relating it to the cognitive needs of designers.

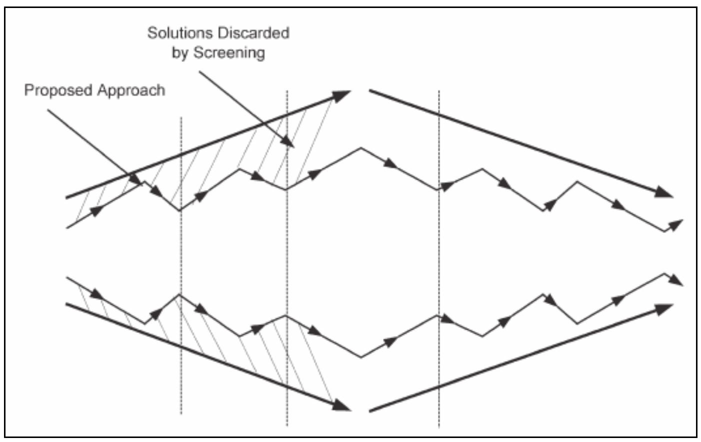


Figure 2.5. Multiple divergence-convergence based design strategy as an ideal approach (Liu et al., 2003, p.346).

Reviewing the literature showed that this strategy was also focused by many design researchers without naming it exactly the multiple divergence-convergence approach. Roozenburg and Eekels (1994) also stated that “working out all solution variants through all phases would lead to an explosion of the number of possibilities to be studies” (p.109). To overcome this challenge, they suggested divergent and convergent activities throughout the entire design process in order to manage with a proper number of solutions and not to overlook any possible alternative (Figure 2.6).

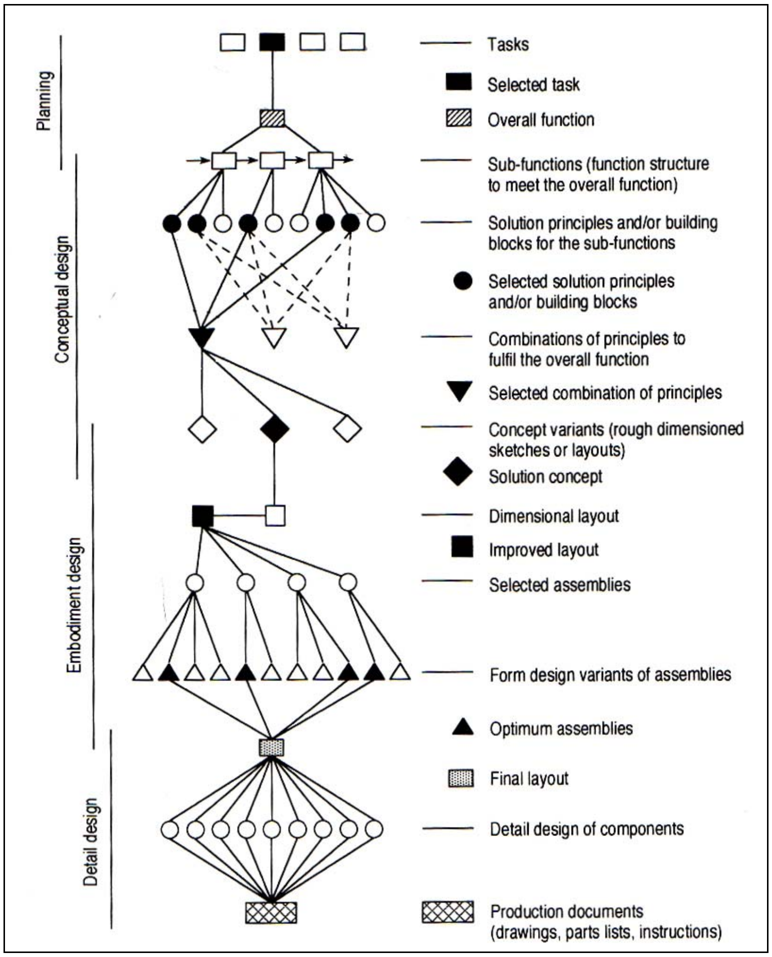


Figure 2.6. Divergence and convergence in the design process (Roozenburg and Eekels, 1994, p.110).

Fricke (1996) investigated designers' tactics to find the most successful method for solution search and noticed that the balanced search which is composed of multiple divergent and convergent activities have led the most successful designs. Dorst and

Cross (2001) analyzed Maher et al.'s (1996) co-evolution model of the problem/solution domain regarding the creativity in design process. They concluded that creative design is a matter of the divergent and convergent steps together rather than first fixing the problem and then searching for a satisfactory solution. Thus, they related creativity in design to the outcome of developing and refining together both the formulation of the problem and the generation of ideas for a solution through the iterative processes of analysis, synthesis and evaluation. Recently, Mulet and Vidal (2006) analyzed the effectiveness of the multiple divergence-convergence based design strategy as proposed by Liu et al. (2003) to improve the functions of a computer-based design support system. They conducted an experimental study, in which the results were coincided with Liu et al.'s (2003) scheme and indicated the strong relationship of the multiple divergence-convergence based design strategy with the successes of analyzing, synthesizing and evaluating of the solution alternatives.

## 2.4 Cognitive Needs of Designers during the Conceptual Design Phase of Universal Design Problem-Solving

Universal design problem-solving is a cognitively challenging task (Levine, 2006; Story, 2001; Story et al., 1998). The sequence of the cognitive design actions throughout the universal design process rests on a continuous process of interactions between the formulation of the universal design problem and generation of the solution alternatives (Ostroff, 2001; 2003). Since a universal design problem is a multi-constraint problem and working out all of these constraints within the network of solution possibilities is difficult. Therefore, it is essential to assist the cognitive skills and needs of designers in universal problem-solving process. However, there is a limited number of design studies and CAD investigations on the nature of design cognition that supports the cognitive activities of universal design process in the conceptual phase (Beecher and Paquet, 2005). The developed CAD systems do not support systematically the designers in a range of situations that encourage universal design. The studies should go beyond the modeling of human dimensions, visualization of ergonomics data and task analyses to consider CAD development as a human activity (Meniru et al., 2003). "Each of these systems provides support for design representation, manipulation, transformation and analysis, but none of them explicitly support architects' cognitive needs" (Robbins et al., 1998, p.265). Thus, this study focuses on the cognitive aspects of universal design operations that respond to the cognitive needs of designers within the CAUD environment.

Cognitive needs of designers in universal design problem-solving can be studied both by focusing on the universal design activity and designer's behaviour. Design activity in the literature is most commonly explained under analysis-synthesis-evaluation model (Carrara and Kalay, 1994; Lawson, 1990; Roozenburg and Eekels, 1994). Thus, this study defines universal design activity as an iterative process composed of these three main operations of the architectural design process:

(1) Defining a set of objectives (analysis),

(2) Generating alternative design solutions in relation to the defined objectives (synthesis)

(3) Evaluating the solution alternatives (evaluation).

However, these three operations are not sequentially executed. They are thoroughly intertwined because of the complexity of the design task. Their sequence is left to the cognitive operations of the designer conducted within her/his brain (Lawson, 1990). Therefore, understanding and supporting the cognitive needs of designers in each operation is crucial for the success of the final solution. The following three sections draw the necessary CAUD specifications for each operation in order to create an ideal CAUD plug-in tool that assists cognitive needs of the designers in the universal design problem-solving process.

### 2.4.1 Analysis Needs

Analysis operation as the initial part of the conceptual design phase requires defining the list of objectives. Roozenburg and Eekels (1994) defined the list of objectives as the design specifications that "are the normative properties about a new product should have, which sets limits to the solution space, and indicates the solutions are preferred ones" (p.131). However, this design specification does not designate the problem or solution but only provides a sufficient problem-solution description regarding the requirements of the project (Akin, 1986). Ozkaya and Akin (2006) described the requirement specification and design development as parallel activities since the design act involves a cyclic process in which the design alternatives are checked against the initial set of requirements, and the set of requirements are redefined for the subsequent steps. While defining and re-defining the set of requirements, the cognitive behaviour of the designer is composed of the interactions and interpretations between verbally expressed design goals and visually created images (Goldscmidt, 1994; Lipson and Shpitalni, 2000). When drawing or reviewing a sketch, the designer makes decisions by switching between the sketches and requirement information. Frequently revisiting the listed design objectives and requirements are needed in order to modify/add/specify new ones to the initially stated requirements. So requirement definitions of the objectives are not static and they evolve as the conceptual design process develops (Dorst and Cross, 2001). However, the "computational design support tools for integrating requirement management with design exploration do not exist" (Ozkaya and Akin, 2007). Therefore, designers use office applications, such as spread sheets and data bases, which are slow, inefficient and not capable of supporting designers' cognitive needs during the analysis operation. In this respect, the CAUD plug-in tool that integrates the requirement management to design exploration is different than the office applications.

Examining the literature on universal design problem-solving emphasized the importance of analysis operation in the success of universal design solutions. Defining the objectives of universal design requires a broader design thinking within the context of a given design project that includes the accessibility codes and standards, usability issues, building code specifications and latest trends in universal design (Levine, 2006; Canadian Human Rights Commission, 2006). Therefore, the universal design problem-solving process evolves as a result of numerous, interrelated design decisions based on the diverse requirement values. Initial definition of each requirement can critically affect the solution alternatives in the later design phases, and each new definition of the later requirements has the potential of requiring the backtracking of the previous requirement decision (Levine, 2006; Story, 2001). However, there is a deficiency in the current universal design practice. Designers rarely evaluate universal design principles of the conceptual design phase because of the difficulty to follow, organize, access and use these requirements (Marshall et al., 2004; Porter et al., 2004). “In applying the principles, there may be conflicts between issues, and the designer should decide upon the priorities of these issues” (Demirkan, 2007). Therefore, designers need to be supported in specifying a priority list of their relevant universal design objectives and parameters. Moreover, they have an access to these specified parameters in order to easily see and check the previous parameters decisions at any session of the universal design process.

### 2.4.2 Synthesis Needs

Synthesis is the design operation in which the multiple divergence-convergence design strategies take place. Roozenburg and Eekels (1994) defined synthesis as the moment of externalization and description of an idea either in the form of a sketch, drawing or model. Synthesis is thinking up solutions regarding the specified list of objectives and checking whether these solution alternatives satisfy these specifications (Mulet and Vidal, 2006). During synthesis “divergent and convergent activities alternate constantly, because there is never just one solution” (Roozenburg and Eekels, 1994, p.176). Transforming the solutions from one abstract solution level to the next more detailed level is the most challenging requirement of the synthesis operation (Liu et al., 2003). Thus, designers need to be supported during their divergent and convergent thinking process. They require a successful linking mechanism between each requirement and solution alternative (Ozkaya and Akin, 2006). Moreover, designers should be assisted in retrieving the relevant visual and verbal design information for each alternative (Vries and Jong, 1997). Designers can benefit from this information when it is delivered to them via design critics. Critic-based approach provides the basis for decision-making process of designers during synthesis (Fischer et al., 1993; Robbins et al., 1998; Sumner et al., 1997). The cognitive theory of reflection-in-action (Schon, 1983) emphasized the importance of design critics and suggested that “design environments must provide feedback to support decision-making in the context of partial designs, i.e. while designs are being manipulated” (Robbins et al, 1998, p.263). Moreover, a successful synthesis of design solutions requires designers to be creative (Candy, 1997; Cross; 2006; Fischer et al., 1993; Mulet and Vidal, 2006). In this respect, any active critic feedback mechanism that can interrupt designer’s creative process should be avoided. Rather passive feedback systems should be developed.

As well as exploring the new creative design alternatives, the existing designs and use-cases also play an essential role while stimulating the generation of creative design alternatives. A case-based system has the potential to help designers to produce new solutions by adapting and reusing the previous solutions for the current situations (Oxman and Oxman, 1994; Flemming, 1994). Also, using case-based systems allows designers to employ the relevant design information from the existing designs into a new design context (Smith et al, 1996; Voss et al., 1996).

Generating universal design alternatives requires a way of thinking, in which the synthesis of solutions is guided both by the specified list of requirements and relevant universal design parameters. Therefore, a CAUD plug-in tool should provide both visual and verbal means for design guidelines and dimensional standards through which the designer can be informed about the required parameter values. Such design guidance that is supported through critic-based systems can suggest better design values and help designers to make successful universal design decisions. Moreover, an efficient CAUD plug-in tool should support designers by providing the exemplary use cases regarding the critical dimensions and recent creative advancements in universal design. Such a catalog consisting of the previous universal design solutions can assist designers to revise their alternatives according to the mandatory minimum technical specifications and minimum code requirements of universal design. It can also allow designers to interpret their solution alternatives from different perspectives of universal design.

### 2.4.3 Evaluation Needs

Evaluation is assessing and comparing the expected performances of the emerging solution with the specified objectives (Carrara and Kalay, 1994). A solution is satisfactory as far as it meets the objectives of the design specification (Roozenburg and Eekels, 1994). However, the evaluation and selection of the most satisfactory solution from a wide range of solution alternatives is often subjective and a challenging task to carry out reliably within a CAD environment (Liu et al., 2003). "Designers in practice would find it difficult to complete the evaluation job because of the very large number of designs to be evaluated" (Liu et al., 2003, p.247). Thus, it is essential to support designers so that they can carry out the evaluation in a progressive and disciplined manner (Pugh, 1991). Although, the designers have developed decision methods such as weighted objectives, factor scale scores, or checklists that lead them to make objective evaluation for better design decisions (Roozenburg and Eekels, 1994), they are not sufficient to respond to the cognitive activities of designers when they are using a computational medium for universal design problem-solving.

Universal design problem-solving requires an understanding of an evaluation operation that involves two categories: namely, one is the design specifications and the other is the universal design parameters. Examining the design literature revealed that there are studies on universal design evaluation that attempt to either evaluate the final products or built environments or their prototypes by checking their compliance to the principles of universal design. Story et al. (2000) suggested a five-point rating scale of universal design performance measures for evaluating how well the products satisfy the principles of universal design by coding from ‘strongly agree’ to ‘strongly disagree’. Also, Preiser’s (2001; 2003) universal design evaluation process models are based on Post-Occupancy-Evaluation (POE) and Building Performance Evaluation (BPE). In these evaluation models universal design performance criteria are derived from the client needs and physically measurable characteristics of the building type that are combined with seven principles of universal design. Beecher and Paquet (2005) developed a universal design measurement tool that allows designers to evaluate their prototype products systematically on a number of different dimensions that are related to the seven principles of universal design. Levine (2006) designed a universal design audit checklist that evaluates the properness of each building element in terms of its usability level.

However, there are still many questions in the use of such evaluation operations within a CAD environment. The researchers considered universal design evaluation of either the products or buildings in the final or occupational design phase rather than the conceptual phase as the most important phase of universal design problem-solving. In this respect, designers need a CAUD medium that can provide an effective universal design evaluation within the potentials of the computational medium. Moreover, such a medium should be designed considering its usage during the cognitive activities of conceptual design phase. It should also support a universal design evaluation based on objective assessments and levels of priority rather than subjective and experience-based (Preiser, 2003).

## 2.5 Proposed Model

Taking into consideration the approaches explained in literature review, the study developed the structure model of the CAUD plug-in tool based on Eastman's (1999) typical structure for a modern CAD system. The proposed model is illustrated in Figure 2.7. It is composed of three main environments; modeling, application language and universal design. Each environment is composed of software modules that are shown by the boxes with multiple inputs/outputs. The next sections deal with each environment in detail.

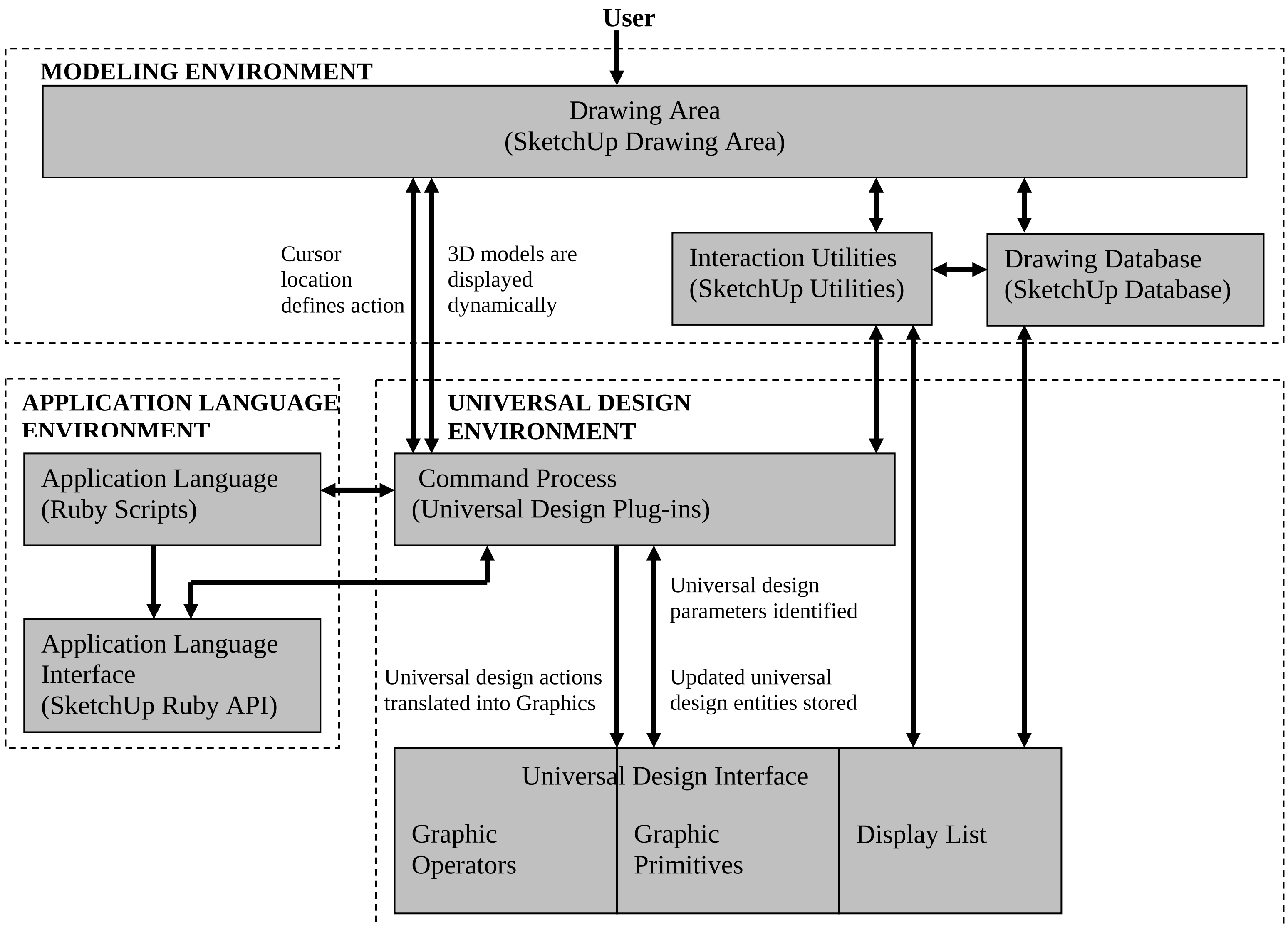


Figure 2.7. Structure of the proposed CAUD plug-in tool adapted from Eastman's (1999) typical structure.

## 2.6 Modeling Environment

In modeling environment SketchUp Pro 5 version (SketchUp, 2006) is used to provide computer support in the conceptual design phase of universal design process. It is a 3D modeling program designed for professional architects, civil engineers, filmmakers, game developers, and related professions (SketchUp, 2006). It is marketed as an easy-to-use conceptual tool with its simple graphical interface features.

### 2.6.1 Drawing Area

SketchUp drawing area is the screen where users create their 3D projects. It receives all user inputs and transfers them to the 'command processor'. The 3D space of the drawing area is identified visually by the three drawing axes (SketchUp User's Guide, 2006). As seen in Figure 2.8, there are menus and toolbars in the drawing area that allow designers to define design actions through the mouse selections and keyboard shortcuts (SketchUp, 2006). Drawing area also displays dimensional information through display status bar while users draw 3D projects.

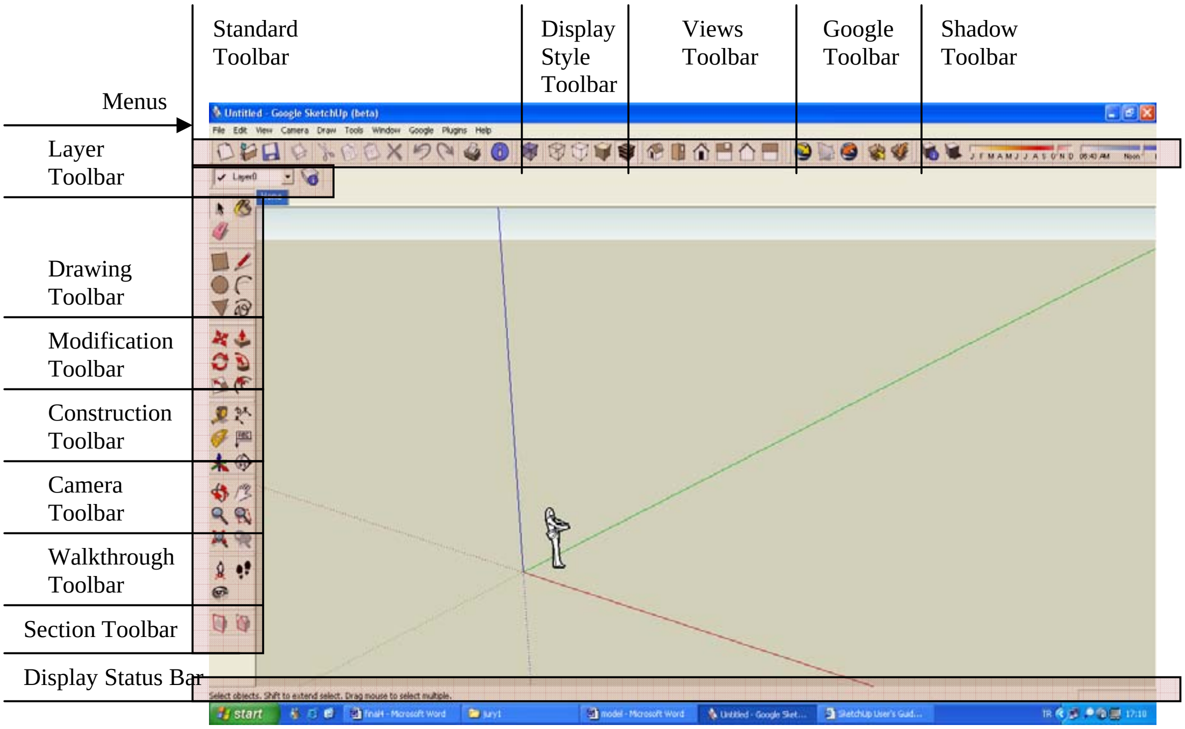


Figure 2.8. Menus and toolbars in the SketchUp drawing area.

### 2.6.2 Interaction Utilities

The ‘interaction utilities’ are the tools that provide information to the user as real-time coordinates of the interactions and are not directly related to the project database (Eastman, 1999). SketchUp interaction utilities allow users to interact with their 3D projects and to modify the existing geometry through the menus and toolbars shown in Figure 2.8 (SketchUp User’s Guide, 2006). Compared to the other 3D modeling environments developed for the conceptual design phase, SketchUp provides two new innovative CAD features for the proposed CAUD plug-in tool in addition to the standard modeling operations such as move, rotate, scale, offset and intersect

(SketchUp, 2006). The first feature is ‘SketchUp’s Push/Pull tool’ that is based on a push and pull metaphor. As the name implies, it provides an effective extrusion interface for users in extruding easily 2D shapes into 3D only by clicking simply on the shapes and pushing or pulling them (SketchUp, 2006). Cherlin et al. (2005) claimed that this interface was more advantageous compared to the conventional Boolean CAD methods. They further added that it allowed designers to sketch quickly 3D drawings of products, buildings, built environments and urban fabrics by offering direct manipulations over faces and edges.

The second SketchUp interaction utility feature is its support for a web-based collaboration design environment through Internet. The Google toolbar (see Figure 2.8) within SketchUp provides designers to interact with other Google technologies, such as Google Earth (SketchUp User’s Guide, 2006). Besides, designers can place their 3D projects in Google Earth at an intended location by using the buttons on the Google toolbar. Further, SketchUp also works well with the other CAD solid modeling tools, such as AutoCad, AutoDesk Revit, Graphisoft ArchiCAD, 3D Studio, Maya, ArcGIS etc (SketchUp, 2006). The outputs can be obtained at a variety of file formats, such as DWG, DXF, PLN, 3DS, OBJ, JPEG, TIFF, etc. Thus, designers can easily interact with their 3D projects in the next phases of design process by importing/exporting them from SketchUp to other solid modeling tools.

### 2.6.3 Drawing Database

SketchUp drawing database is composed of various entities that are either stored as a single entity or library components (SketchUp User's Guide, 2006). The single entities include surfaces, faces, arcs, curves, lines, 3D polylines and polygons. Users can create their 3D projects either from these entities or combining several entities to construct components and store them in the component library. Moreover, SketchUp has a connection to a collaborative library named Google 3D Warehouse through the 'Google toolbar' (SketchUp, 2006; SketchUp User's Guide, 2006), from where users can download a project/ a drawing into the drawing area. This feature allows designers to search, share, and store their 3D projects within a web-based drawing database (SketchUp, 2006). As a result of these above-explained SketchUp's features, SketchUp Pro 5 is preferred as a CAD package for the study to develop a CAUD plug-in tool supporting the conceptual design phase.

## 2.7 Application Language Environment

Application language environment is composed of Ruby scripts as the application language with the SketchUp Ruby API as the application language interface. SketchUp Ruby API communicates directly with SketchUp command processor to extend the functionality of SketchUp (See Figure 2.7). The users are able to define new commands for the creation of hundreds of useful/additional tools, macros and plug-ins that are included in the menus and toolbars of SketchUp illustrated in Figure 2.8 (SketchUp Ruby Documentation, 2006).

### 2.7.1 Features of the Application Language

Ruby is an object-oriented (OO) language, which is more simple and easy-to-learn as opposed to the other OO languages, such as C++ and Java (Pine, 2005; Ruby User's Guide, 2006; Thomas et al., 2005). In Ruby, everything that is manipulated is an object; and the results of the manipulations are also objects that mean all objects have 'Object' as an ancestor by default. Ruby OO environment consists of these manipulated objects named classes and modules. A class is a combination of class instances with unique characteristics, instance methods with its related parameters and instance variables (Thomas et al., 2005). Each class has its parent class and each parent class has its superclass. In this respect, all class interactions can be explained depending on a parent-child relationship (Figure 2.9). A module is composed of module methods and constants. Ruby allows to include a module within a class, which is named as mix-in facility (Maeda et al., 2006; Thomas et al., 2005). "When this happens, all the module's methods are suddenly available as methods in the class as well" (Thomas et al., 2005, p.112). The difference between a Ruby class and a Ruby module is that a class may inherit from another class, but not from a module (Maeda et al., 2006). A module's parent is not available. It cannot inherit anything and also, it does not generate a sub-class (Maeda et al., 2006).

**RUBY OO ENVIRONMENT**

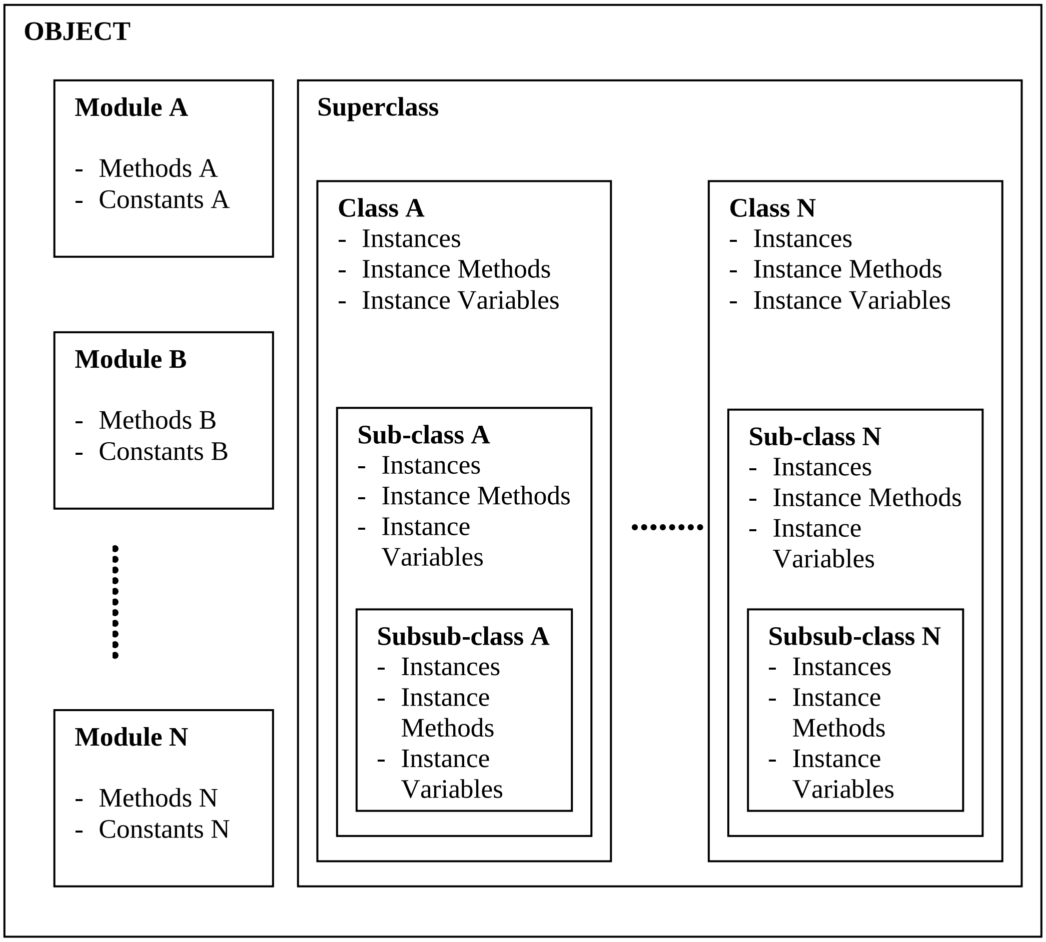


Figure 2.9. Ruby OO Environment with its modules and classes.

Compared to the other OO languages, such as C++, C# and Java, Ruby is more advantageous by supporting the above explained controlled multiple-inheritance hierarchy (Thomas et al., 2005). Within this hierarchy, although a Ruby class has only one direct parent, each ruby class can also inherit functionality from its included modules, its belonging instances, instance methods and variables. To provide a better link between the potentials of Ruby and CAUD plug-in tool, the next section deals with this Ruby hierarchy in detail by explaining it in the SketchUp context.

### 2.7.2 Application Language Interface

SketchUp Ruby API as an application language interface supports the creation of customized features according to designers' specific intentions and manipulation of geometry in SketchUp. The API is composed of a series of SketchUp-specific Ruby classes and modules. This study categorizes these classes and modules in order to explain systematically their function in each SketchUp feature and the performed task. While systematizing the classes and modules, the 3D modeling concepts of SketchUp User Guide (2006) are used and defined by the author under the six following categories:

(1) SketchUp user interface;

(2) Designing and drawing in SketchUp;

(3) Viewing models in 3D;

(4) Adding detail to the models;

(5) Presenting the models and

(6) Modeling terrain and organic shapes.

The classes and modules of the first category deal with the creation of any visible interface that enables users to interact with the main parts of SketchUp such as menus and toolbars (SketchUp User Guide's, 2006). Second category includes the essential classes and modules for drawing accurately and constructing a 3D project in SketchUp (SketchUp Ruby Documentation, 2006). The next category covers Ruby classes that allow users to manipulate various views in the drawing screen. The classes of the fourth category deal with adding materials and texture on faces from either the existing material library or the created libraries (SketchUp User Guide's, 2006). The fifth category covers classes that allow users to create and manipulate macros for the representation of 3D projects (SketchUp Ruby Documentation, 2006). Last category is composed of classes related to the manipulation of continuous smooth surfaces and organic shapes thorough several connected triangular faces .

## 2.8 Universal Design Environment

Universal design environment consists of the universal design plug-in tool and universal design interfaces which are written by SketchUp Ruby API. The universal design interfaces constitute to the access each graphic primitive of the 3D project in the drawing area and to the display of the essential universal design data.

### 2.8.1 Universal Design Plug-in Tool

The universal design plug-in tool provides support for developing and processing relevant universal design data in the conceptual design phase. In this respect, a universal design class named 'UniversalDesign' with a required number of sub-classes is defined for a project. The 'UniversalDesign' class with its sub-classes will provide the mandatory technical universal design specifications, requirements, solution alternatives, dimensional standards and design guidelines for the project, which can be based on the existing universal design knowledge domain that can be retrieved from both the existing literature and directly users through user-centered techniques (Barrier free environments Inc., 1991; Canadian Human Rights Commission, 2006; The Center for Universal Design 1997; 2007a; 2007b; Goldsmith, 1997; Grist et al., 1996; Mullick and Levine, 2001; Young and Pace, 2001). In this respect, for a universal design project designers can dynamically load the developed universal design plug-in tool into SketchUp and interact with two-dimensional (2D) and/or three-dimensional (3D) manipulations of the project according to this predefined universal design knowledge domain through the universal design interface, which is explained in the next section.

### 2.8.2 Universal Design Interface

Universal design interface is designed to be simple and easy to use in relation to the graphical operators of SketchUp. The universal design interface consists of menus and toolbars, through which universal design data can be managed and operated on the graphical primitives and display lists. Menus retrieve a SketchUp's menu object with a given name (SketchUp Ruby Documentation, 2006). In an exemplary kitchen project, which will be elaborated in Chapter 5, the above represented plug-in tool can be created on the "Plugins" menu of SketchUp (Figure 2.10).

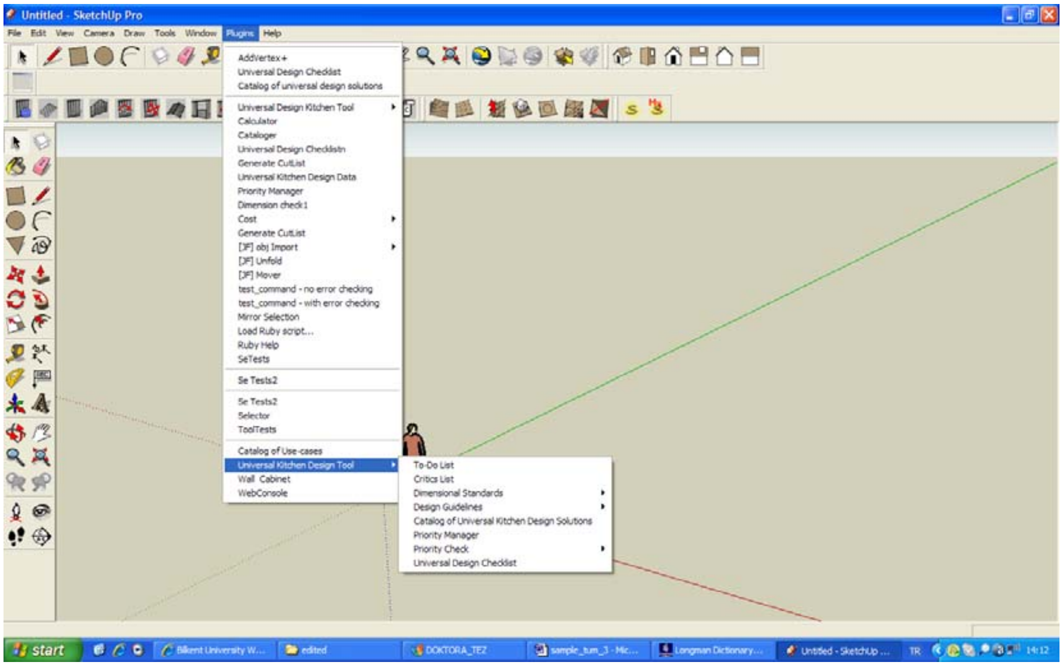


Figure 2.10. Developed CAUD plug-in tool on ‘Plug-ins’ menu.

The developed plug-in tool provides either dialog box, web dialog box and/or message box as the interface element. Through universal design dialog boxes users can manage the required dimensional standards (SketchUp Ruby Documentation, 2006). Dialog boxes provide access to design data in user friendly manner that facilitates effective editing, viewing and creation of design entities in many forms such as text, graphics or relations. Figure 2.11 shows an exemplary maneuvering diameter dialog box for universal kitchen design.

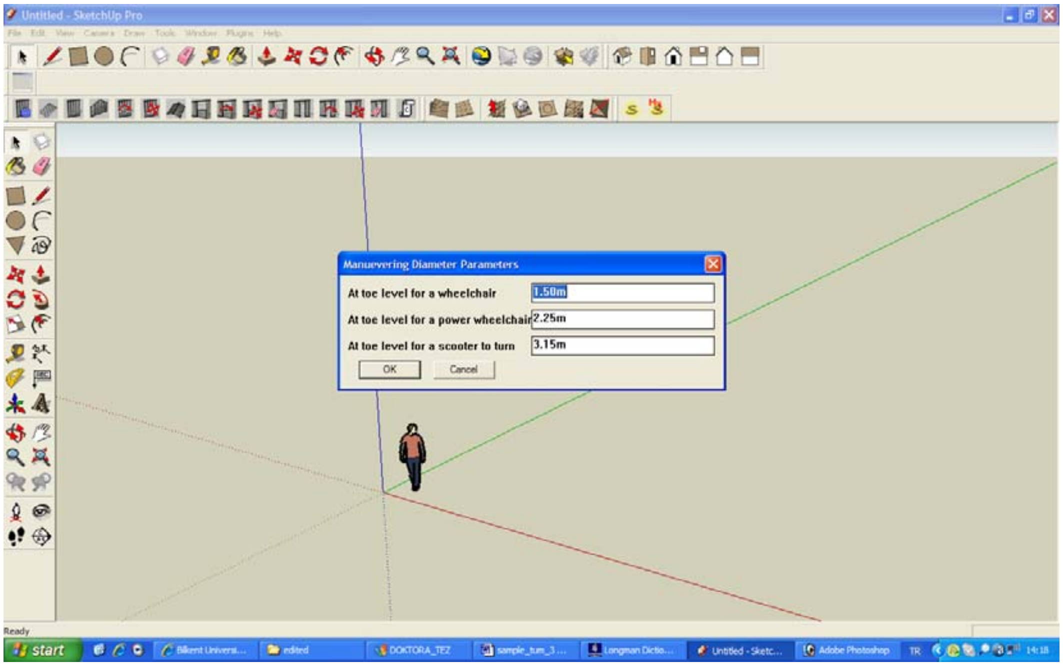


Figure 2.11. An exemplary maneuvering diameter dialog box.

The message boxes are user interface elements that contain relevant written texts (SketchUp Ruby Documentation, 2006). Message boxes provide read-only sections for reminders, comments and additional information for designers. They minimize effort and time to access relevant universal design data by storing data within the drawing environment. They act like internal data bases for design ideas. Figure 2.12 illustrates an exemplary message box for illumination design guidelines for a universal kitchen design.

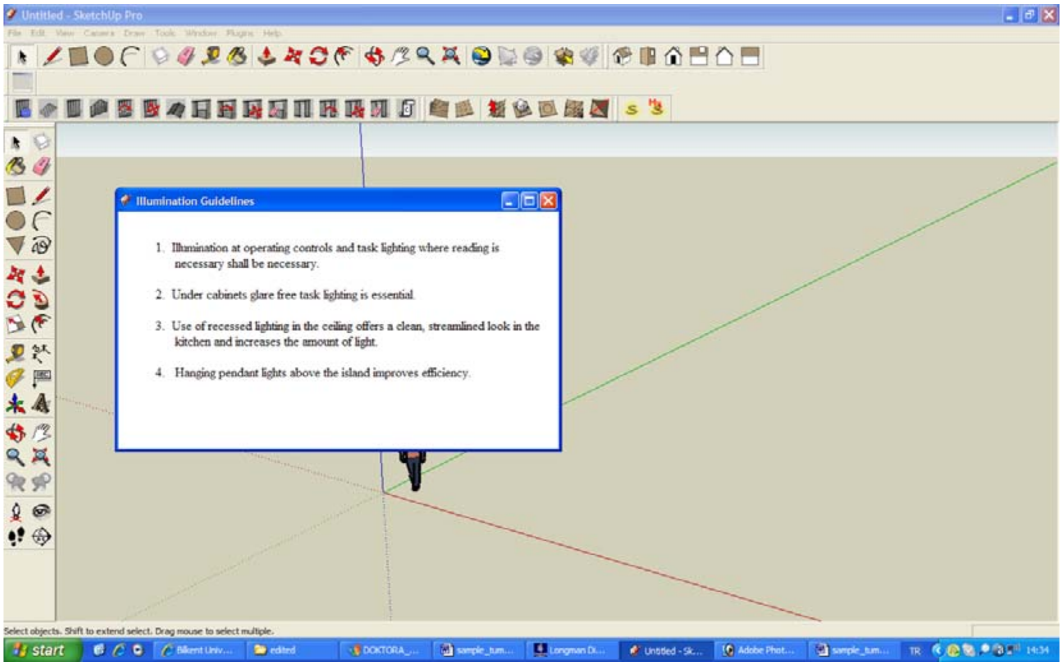


Figure 2.12. An exemplary message box for illumination design guidelines.

Web dialog boxes are interface elements that provide an embedded browser inside the SketchUp software. They can interact with Web and open a browser window, which has a local html file. Web dialog boxes give the ability to use web tools, such as checkboxes, dropdown boxes, option buttons etc., within the SketchUp environment. Their interface offers a mechanism that enables designers to access both text-based and graphically-based data at the same time. Figure 2.13 illustrates an exemplary web dialog box for universal design checklist for a universal kitchen design.

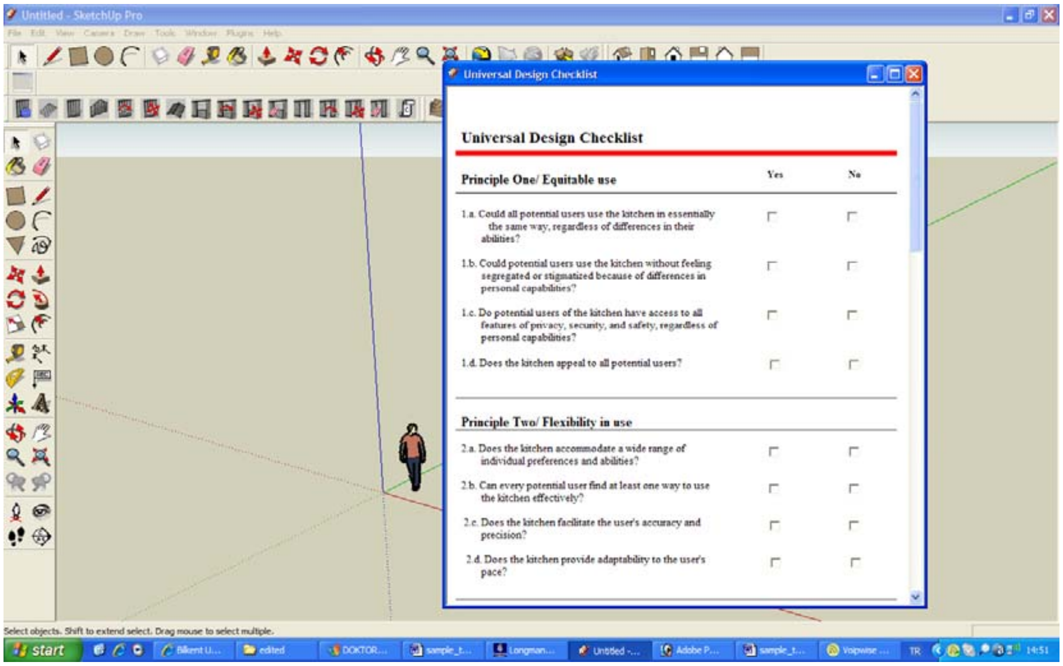


Figure 2.13. An exemplary web dialog box for universal design checklist.

Each of these interfaces is explained in more detail in the following chapter with respect to the capabilities of the CAUD plug-in tool.

# 3. THE CAPABILITIES OF THE CAUD PLUG-IN TOOL

The capabilities of the CAUD plug-in tool are defined according to accommodation with the suitable cognitive strategy and the three above-explained main operation needs of designers. These capabilities add new design and modeling facilities to SketchUp that address the cognitive challenges of the universal design process in the conceptual design phase. They are acting as a key mechanism that supports the digital design information flow from the analysis to the synthesis operation and from the synthesis to the evaluation operation. The CAUD plug-in tool allows the specification of the universal design requirements as well as generation/modification of the universal design solutions. Figure 3.1 illustrates the information flow process regarding the multiple divergent-convergent activities in each operation. This CAUD plug-in tool is capable to support the universal design problem solving process at different levels of solution abstractions, from analysis to evaluation. The structure of the developed plug-ins is adapted from Eastman's (1999) model that depicts the typical structure of a modern CAD system. As illustrated in Figure 3.2, the critic agents support the information flow between the analysis and synthesis or synthesis and evaluation operations. These agents interact with the command processor and universal design interfaces of the software while providing the important source of universal design information and identifying the appropriate universal design knowledge domain to enhance designer's required cognitive strategy. Since the "expert systems are inadequate in situations, where it is difficult to capture sufficient domain knowledge, and leave the human out of the decision process" (Fischer et al., 1991, p.126), the plug-ins that are developed in this study use the critiquing approach. Through the critiquing mechanism during the analysis-synthesis-evaluation operations the design "talks back to the user" (Fischer et al., 1991, p.123) so that designer has the opportunity to modify either the specification list or the solution alternatives according to the specified standards, guidelines and requirements of universal design.

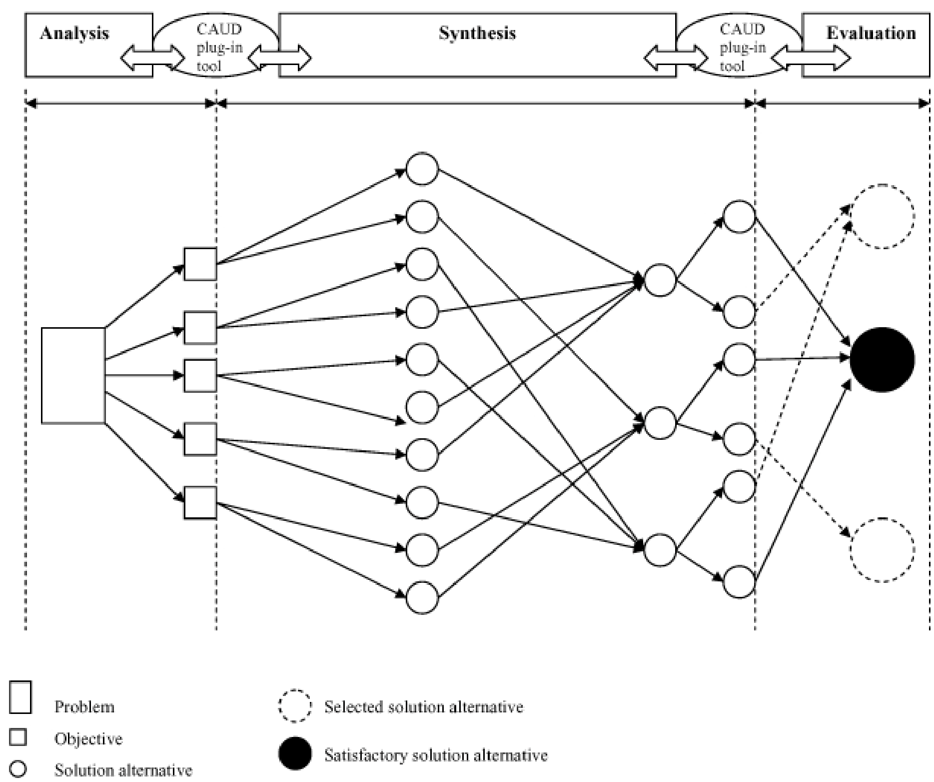


Figure 3.1. Overview of the CAUD plug-in tool's information flow.

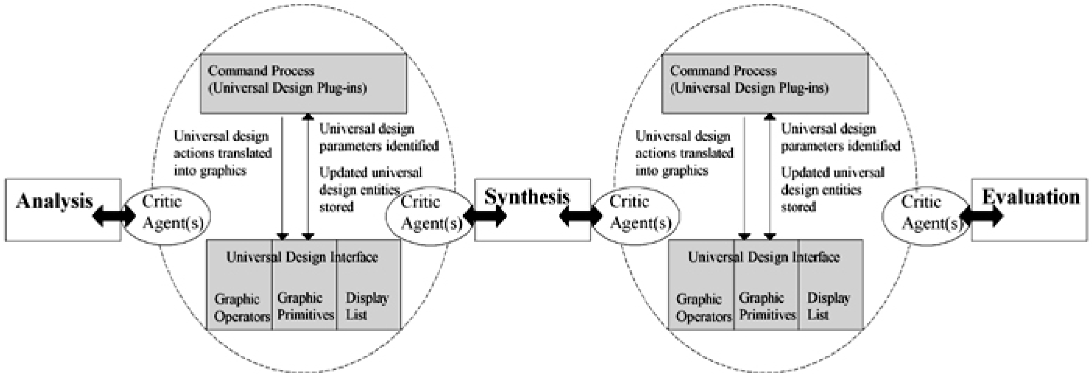


Figure 3.2. The critic agents of the CAUD plug-in tool.

The CAUD plug-in tool focuses on the required design manipulations and universal design knowledge support during the multiple divergent-convergent decisions of designer during the conceptual design phase. In this respect, it is also essential to overview these capabilities and how they address the suitable cognitive strategy of universal design process. The information flow in the universal design knowledge support scheme of the CAUD plug-in tool is explained with respect to the analysis/synthesis/evaluation operation needs of designers. In the analysis operation, the CAUD plug-in tool can increase the effectiveness in the formulation of the design problem by the universal design to-do list. In the synthesis operation, the plug-in tool can support the generation of universal design alternatives by providing the relevant dimensional standards and design guidelines, examples of the previous universal design solutions and critics of either specific cases or design team members**.** In the evaluation operation, the plug-in tool can help in refining the solution alternatives by assessing its correctness against to the predefined priorities and seven principles of universal design. In this study, the current implementation of these capabilities of the

CAUD plug-in tool is only limited to the interior design applications. The following five sections explain each capability in detail and illustrate exemplary interface designs. The detailed implementation of each capability is carried out in Chapter 5, which deals with the overall development and implementation of the plug-in tool for a universal kitchen design.

### 3.1 To-Do List

The 'To-Do List' interface is designed to support designers during the analysis operation. This interface provides the list of the specified universal design specifications and helps to organize/store/present each specification in an appropriate format. It also acts as a control mechanism to keep track of the status of each specification through the usage of 'done' checkbox and date input information. Such a mechanism is crucial in complex design situations as universal design. It can either work as a passive reminder for designers to complete the unfinished specifications in generating solutions and/or adding new specifications that are emerging from the generated solution alternatives. In this respect, the design process and the specification of the requirements are carried out as parallel activities. Briefly, a to-do list item contains the list of the requirement description with the assigned status and priority level for each item and the add/delete buttons. These features of the universal design to-do list items help designers to manipulate the specification changes that take during the conceptual phase of the universal design process. Figure 3.3 illustrates an exemplary ‘To-Do List’ interface' for a universal kitchen case.

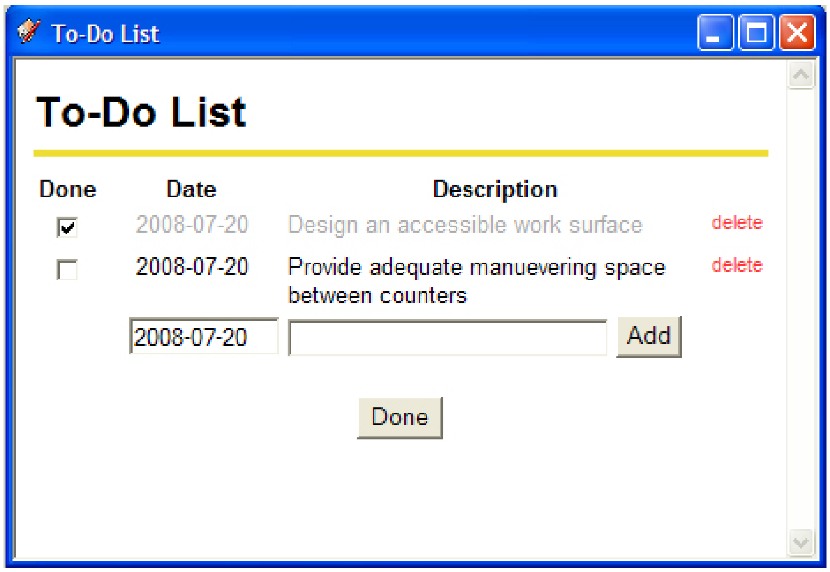


Figure 3.3. An exemplary ‘To-Do List’ interface.

## 3.2 Feedbacks from Critiques

Critique feedbacks assist designers during the synthesis operation and multiple divergent-convergent activities through the ‘Dimensional Standards’ and ‘Design Guidelines’ interfaces. Designers make numerous and diverse universal design decisions to achieve a satisfactory universal design decision. Critique feedbacks supply the relevant information on the dimensional standards via dialog boxes and design guidelines via message boxes. The dimensional standards provide the parameter values and the mandatory minimum technical specifications for a particular design element. The design guidelines deliver designers the knowledge support in the form of recommendations for the revision of design in order to make an accessible and usable design space for everyone. Experiences on the critiquing systems showed that active critics are not a perfect solution and can disrupt designer's concentration (Fischer et al., 1993). In this respect, the critic interfaces within the CAUD plug-in tool can be activated by designer by activating the relevant item from the Plug-ins menu of SketchUp. In the study for a universal kitchen design, dimensional standards are presented under five sub-menu items: 'Maneuvering Diameter Parameters'; 'Knee Space Parameters'; 'Reach Range Parameters'; 'Work Triangle Parameters' and 'Clearance at Appliances'. Design guidelines are presented under two sub-menu items: 'Illumination Guidelines' and 'Material Guidelines'. These passive critic feedbacks inform designers about the existing knowledge domain on universal design. This study uses the knowledge domain of the *International Best Practices in Universal Design* (Canadian Human Rights Commission, 2006), in which the Canadian accessibility codes and standards for both buildings and landscapes are examined in relation to other international codes and standards from the United Kingdom, the United States, China, Japan, Australia, the Nordic countries and Fiji in order to determine the best practices based upon universal design principles. Figure 3.4 illustrates one of the 'Dimensional Standards' interface, 'Reach Range Parameters' and Figure 3.5 illustrates one of the 'Design Guideline' interface, 'Material Guidelines'.

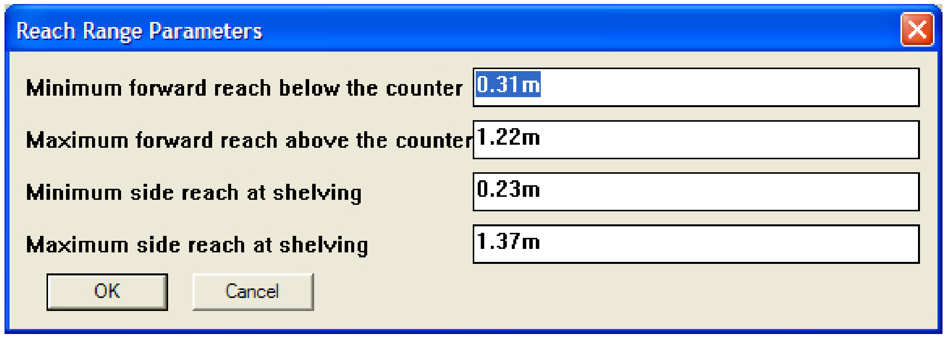


Figure 3.4. An exemplary ‘Dimensional Standards’ interface for reach ranges.

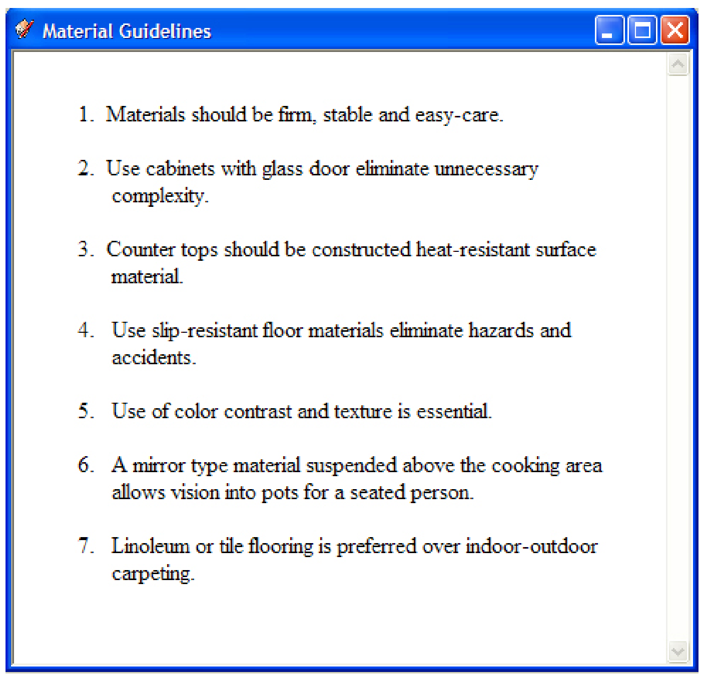


Figure 3.5. An exemplary ‘Design Guideline’ interface for materials.

## 3.3 Catalog of Universal Kitchen Design Solutions

The catalog of the previous design solutions provides information to designers about the case studies on universal kitchen design. For the universal design domain, a case consists of relevant knowledge from the best universal design solutions regarding diverse user needs, expectations and capabilities together with the specific design solutions. In this respect, a case based reasoning technique can be used to achieve satisfactory universal designs by retrieving associated solutions for each problem description. Designer is informed about architectural plans, sections, photographs, dimensional and/or textual information of previous universal design use-cases by choosing the appropriate keyword on the interface. Moreover, there can also be some web site links that can be activated from this interface since some of the recent case studies on universal design are also available in html format. In this respect, finding either visual or textual references of universal design can support the synthesis operation and the multiple divergence-convergence cognitive strategy of designers that can encourage them to develop more promising and creative universal design concepts. Figure 3.6 illustrates an exemplary ‘Catalog of Universal Kitchen Design Solutions’ interface for a universal kitchen case.

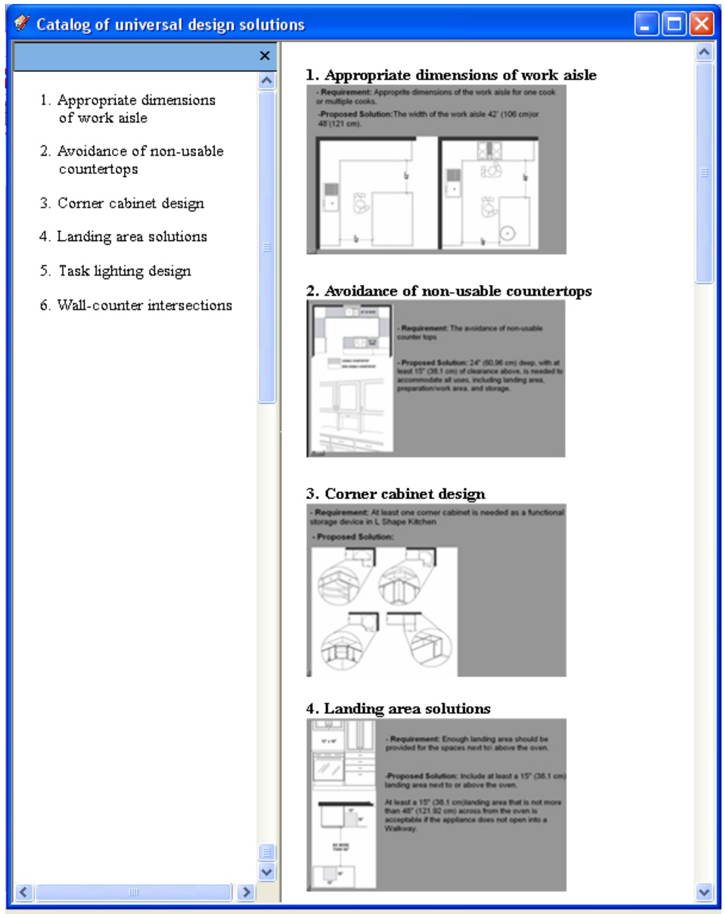


Figure 3.6. An exemplary 'Catalog of Universal Kitchen Design Solutions' interface.

## 3.4 Feedbacks from Critics

Interactions with other designers in the design community guide the evolution of critics (Robbins, et al. 1998). Even experienced designers need knowledge support. In this respect, critics given by other universal design specialists have also an important role during universal design process. In this respect, the 'Critic List' interface is designed to support the critic feedback from other designers. The critic of other designers is essential in terms of suggesting new universal design alternatives to the current design solution. Since SketchUp provides its users a collaborative web-based computational environment, its users commonly share their models and the relevant information with the other users all over the world. Designers can download other designers' projects to critic on existing design features and/or to suggest new features that can be added as new specifications to a critic list. Then, critics and/or new specification descriptions are saved and loaded to the SketchUp' web-based library that are available to designer next time when the project is downloaded. This process can be also carried out through e-mail trackings. A critic list item includes the date of the given critic, nick/name of the designer, description of the critic and the add/delete buttons (Figure 3.7).

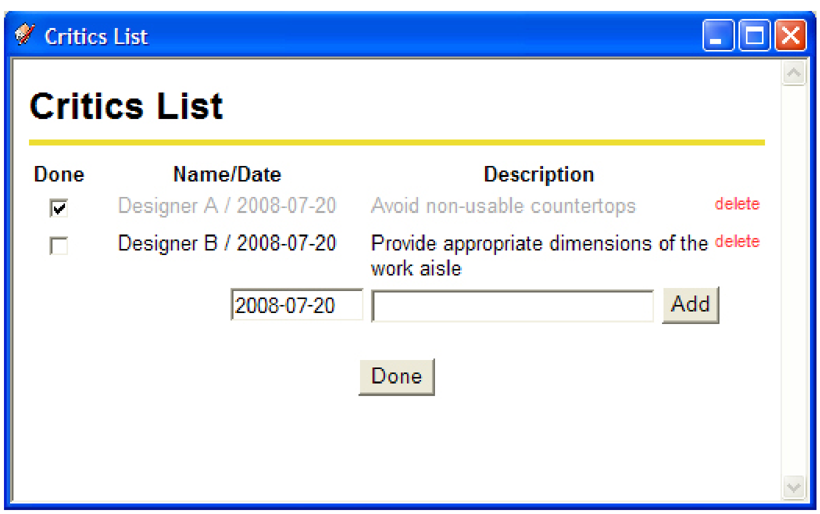


Figure 3.7. An exemplary 'Critic List' interface.

## 3.5 Universal Design Evaluation

Universal design evaluation capability of the CAUD plug-in tool supports designers to select the most satisfactory universal design solution. It consists of the ‘Priority Check’ and the ‘Universal Design Checklist’ interfaces. The ‘Priority Check’ interface, which evaluates a design feature for whatever universal design parameter values have been defined for this feature, will be mentioned in detail in Chapter 5. ‘Universal Design Checklist’ interface is adapted from the universal design performance measures of products developed by Story et al. (2000) (See Figure 3.8). This interface supports the designer to identify the potential areas of the current design solution that need an improvement. Moreover, it assists designers to evaluate how well the universal design features of each space satisfy the principles and guidelines of universal design. In this respect, the ‘Universal Design Checklist’ interface provides universal design evaluation after the design decisions are made. These twofold evaluation capabilities of the plug-in tool provide a computational platform which can ensure that the universal design decisions taken in the analysis and synthesis are right ones.

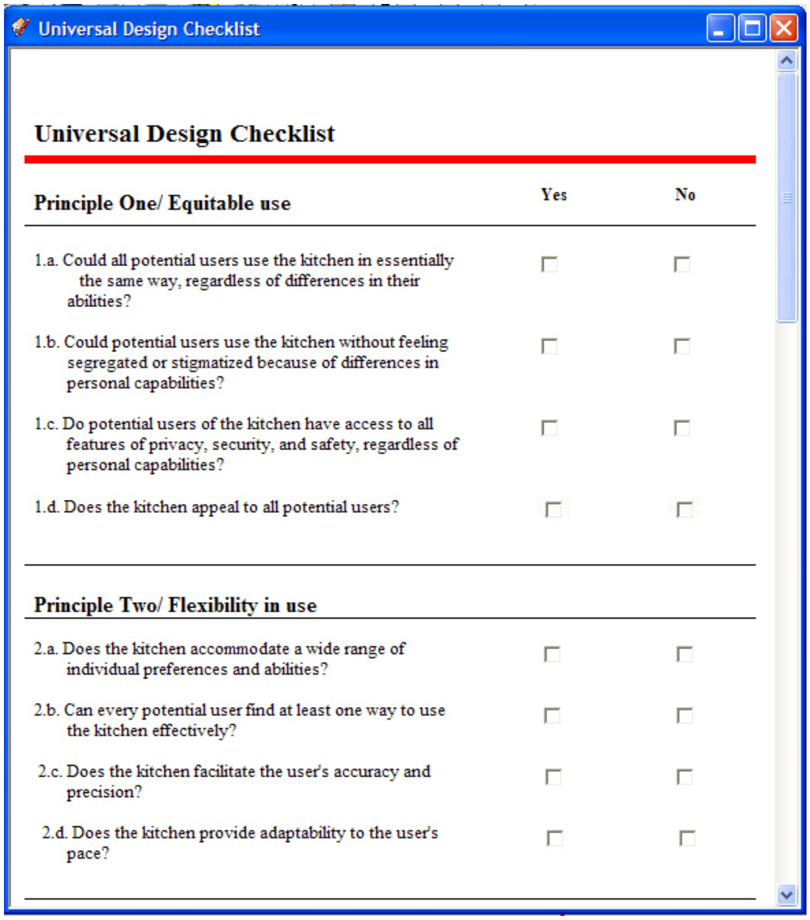


Figure 3.8. An exemplary 'Universal Design Checklist' interface.

# 4. SPECIFICATION AND PRIORITIZATION OF DESIGN REQUIREMENTS TO COMPUTE UNIVERSAL DESIGN PROBLEM-SOLVING

The process of selecting the right set of universal kitchen design requirements involves two challenges. These are the prioritization of the set of universal design requirements and the development of an interface tool for supporting the evaluation of alternative design solutions with the specified priorities. Regarding these two challenges, the CAUD plug-in tool is developed that provides an effective systematic support in assigning priorities to the specified universal design requirements. The plug-in tool also contains evaluation components to resolve the conflicts and trade-offs between the project relevant parameters. This part of the study only focuses on the selection and prioritization of the appropriate design requirements for a universal kitchen. The relationships between each requirement priority are presented in terms of relative importance degrees and later, interfaced into the CAUD plug-in tool.

## 4.1 The Process of Selecting the Right Set of Requirements

The goal of universal design approach is to achieve a performance level that can be measured by the degree of universal design requirements of a specific project are fulfilled (Preiser, 2001). It requires the simultaneous assessment of multiple universal design parameters and principles. This multiple parameter decision making in universal design process especially makes difficult the conceptual design phase, where designers have to deal with most of the conflicting design decisions simultaneously. Since all design decisions cannot be equally satisfied, a designer must determine the relative importance of one requirement to another, which is called its local weight, and the overall relative importance of each requirement with respect to the whole system, which is called its global weight. The choice of candidate requirements for implementation and determination of their strength and importance degrees are primary determinants of user satisfaction (Karlsson and Ryan, 1996). Thus, the universal design requirements need to be prioritized to resolve the conflicts between the parameters and to support the inevitable trade-off in decision making.

Despite the extensive literature on requirements prioritization in software development, requirements engineering and product design fields (Isıklar and Buyukozkan, 2007; Lin et al., 2008), there are a limited number of researches on the systematic specification and prioritization of universal design requirements in architectural design context (Canadian Human Rights Commission, 2006; The Center for Universal Design, 2007a, 2007b). Similar to requirements in engineering studies, architectural design process also needs analysis and prioritization of the requirements. However, most of the studies do not involve an efficient decision support system for a requirement prioritization process and an effective integration of the appropriate multi-criteria evaluation tools into the current computational design medium. Although the process of selecting the right set for universal design requirements are difficult, mostly universal design resources do not provide information on the selection process of the right set of requirements as well as for their prioritization (Demirkan, 2007). Moreover, most of the universal design resources do not provide insight for the requirement-driven design activities, such as elicitation, documentation and validation. Thus, universal design decision making process still heavily relies on the subjective and empirical priority assessment of designers. In order to overcome these gaps in universal design research, the more elaborated prioritization techniques in literature are examined as a means for systematic specification and prioritization of the universal design requirements for the CAUD plug-in tool interface.

## 4.2 An Overview of Requirement Prioritization Techniques for Universal Design

Prioritization of requirements requires a complex context-specific decision making process and should be performed iteratively in every phase of design process (Lehtola et al., 2004). It is especially crucial in the conceptual design phase for supporting the design decisions in order to produce satisfactory design solutions (Karlsson et al., 2007). The term priority can be defined in some cases as the quantity and/or the importance of a requirement, while in other cases it is the degree of how soon a requirement should be implemented (Lehtola et al, 2004). A requirement priority is needed, not just to ignore the least important requirements but also to guide designers in coping with conflicts and trade-offs between multi-attribute requirements simultaneously (Wiegers, 1999).

Because of the challenging and complex nature of prioritizing process, there exist a number of different techniques for requirements prioritization in the literature that can be analyzed under two categories with respect to their usage of ordinal scale or ratio scale (Karlsson et al., 2007; Karlsson et al., 1998). The first category includes prioritizing techniques that result in priorities on an ordinal scale and provide a ranked order among requirements, e.g. the Numerical assignment, the Planning Game (PG), the Quality Function Deployment (QFD), the Bubblesort, and the Binary Search Tree (Beck, 1999). The techniques in the second category provide the results on a ratio scale and provide information on how much more important one requirement is than another. Examples of this category are the Analytical Hierarchy Process (AHP), the Wiegers' method and the 100$ test (Leffingwell and Widrig, 2000; Saaty, 1980; Wiegers, 1999). Karlsson (1996) stated that the techniques based on a ratio scale are more accurate and informative than the ones based on an ordinal scale.

The suitability of a prioritization technique to an application that can help in coping with the challenges of prioritization during conceptual design phase is essential in terms of analyzing the trade-offs between requirements and assigning a local priority to each requirement with respect to others and setting global priorities. According to Karlsson (1996), an efficient and accurate prioritization technique should give a designer the following advantages: (a) a clear means for selecting the right set of requirements for implementation; (b) support to resolve the conflicts between requirements and (c) support to evaluate the alternative design solutions. In this respect, in addition to the ranks of the requirements, the decision maker needs also to know the relative distance between the ordered requirements to achieve an effective trade-off (Liu, 1998). So, to be able to select a suitable prioritization technique for the set of universal design requirements, the following sub-sections describe the three prioritization techniques in detail that are most elaborated and found as the most efficient techniques in literature: the Planning game (PG) (Beck, 1999); the Analytic Hierarchy Process (AHP) (Saaty; 1980) and the modified AHP using cost-value approach (Karlsson, 1996; Karlsson and Ryan, 1997; Karlsson et al., 2007). Each of these three techniques provides an ordered priority list of requirements as an outcome.

### 4.2.1 The Planning Game (PG) Technique

The Planning Game (PG) technique is known as the most traditional and well-known requirements prioritization technique in practice (Lehtola and Kauppinen, 2006). This technique uses the sorting algorithm in assigning requirements to one of the three categories described as essential, less essential and nice. The essential category includes requirements, in which the system will not function without them; the less essential category has requirements that provide significant value and the final category includes requirements that are nice to have with respect to the system performance (Beck, 1999). The PG technique is an easy and straightforward technique, in which “the requirements are presented as a ranking on an ordinal scale without the possibility to see how much more important one requirement is than another” (Karlsson et al., 1998, p.146). Moreover, this technique is helpful in determining the requirements of the next phase by combining the priorities and the technical issues in a short time (Beck, 1999). It is also named as the Priority Groups, in which the requirements are grouped into one of the three priority groups related to their importance level named as high, medium and low (Karlsson et al, 1998).

The PG technique aims to put the most valuable requirement into design as agile as possible (Beck, 1999). This technique is successful if the overall approach is quick and easy; and the requirements can be already written on playing cards (Beck, 1999). It can be conducted either with story cards or task cards depending on the project requirements. The story cards are mostly developed from use cases. The story attributes as technical or financial can also be written on the story cards. In task cards, each requirement is written on a card based on a project specific task assignment. Decision makers can also define a new story or task with respect to users’ needs and demands that is not written on the existing cards. This leads to achieve a better overall quality of designs without missing any essential requirement (Kettunen and

Laanti, 2005). Moreover, the permissible iterations of the PG technique provide decision makers the capability of tracking every design phase that complies with the needs and expectations of users throughout the whole design process. Then, each iteration contains an agreed set of stories and tasks (Wagner, 2001). This iterative technique allows designers to manage changes to requirements, maintain traceability, implement requirements as early as possible and plan their next-phase design activities with respect to the changing users' needs (Kettunen and Laanti, 2005).

There are also researches that address a computational tool support for the PG technique (DotStories by Rees, 2002; StoryManager by Kaariainen, 2006). Although an efficient computational PG tool can provide reliable means for storing, modifying and retrieving information, the users of these tools declared that they were not satisfied with the efficiency and effectiveness of them. They preferred the manual story/task cards and reported that the functionality of the computational tools was confusing and had many disadvantages. Lippert et al. (2003) claimed that a computer tool cannot be used for the PG technique, and they further argued that it can be suitable just for writing stories and tasks and printing them out on paper.

### 4.2.2 The Analytic Hierarchy Process (AHP) Technique

The analytic Hierarchy Process (AHP) technique that is originally proposed by Saaty (1980) is a leading prioritization technique in multi-criteria decision making process.

It is the best-known and the most widely used one (Vaidya and Kumar, 2006). This technique uses pair-wise comparisons for all possible pairs of requirements, in each structured hierarchical level. The primary aim in assessing the relative importance to each requirement is to derive the overall requirement priorities for all solution alternatives in order to determine the ideal solution that satisfies the best priority values (Saaty, 1980).

Besides the quantitative data, the subjective preferences and judgments of decision makers can be utilized in the AHP technique (Leskinen, 2000). So, this technique provides a base for precisely discussing how much one requirement is more important than another. In the AHP technique, the total sum of importance of requirements is equal to 100%. It means that a requirement with an importance of 40% is four times as important as requirement with an importance of 10% (Karlsson and Ryan, 1996). Schoner and Wedley (1989) stated that this technique requires three steps: “structuring the hierarchy, pair-wise comparisons to yield priorities, and synthesis of the priorities into composite measure of the decision alternatives or options” (p.474). In structuring hierarchy as the first step, the complex system is decomposed into subsystems and presented in a hierarchical form, such as a tree diagram. The highest level with only one element is the goal to reach; elements in the middle level are the components of the goal; and elements at the bottom level are the requirements for evaluating those components (Saaty, 1980; Salmeron and Herrero, 2005). In pair-wise comparisons as the second step, all possible pairs of requirements in each level are compared to determine the relative weight of each requirement. If there are n requirements, n (n-1)/2 pair-wise comparisons should be made by using values from a scale. The original scale used by Saaty (1980) for pair-wise comparisons was a one-to-nine point scale (Table 4.1) with the numerical counterparts 1/9, 1/8,…, 1/1, …, 8/1, 9/1. 1/9 means that the value of one requirement is nine times smaller than the value of another and correspondingly, 9/1 indicates that the value of one requirement is nine times bigger than the value of another.

Table 4.1. The original scale of the AHP technique (Saaty, 1980).

| Intensity of importance | Definition |
|---|---|
| 1 | Equal importance |
| 3 | Moderate importance of one over another |
| 5 | Essential or strong importance |
| 7 | Very strong importance |
| 9 | Extreme importance |
| 2,4,6,8 | Intermediate values between the two adjacent judgments |
| Reciprocals | If requirement i has one of the above numbers assigned to it when compared with requirement j, then j has the reciprocal value when compared with i. |

However, there are discussions on the appropriateness of Saaty's (1980) original scale. Some argued that being restricted to a bounded scale can lead the decision makers to certain inconsistent comparisons and unfaithful representations of the problem (Jensen, 1984; Leskinen, 2000; 2007). Moreover, (Leskinen, 2000) said that "scale independence is a desirable feature because the value of the scale parameter might not be accurately known in practice" (p.164). Besides, the ability of humans in expressing their own knowledge decreases both with an increase in the problem complexity and in the number of comparison pairs. Therefore, the AHP technique is likely to result in inconsistent judgments. Thus, decision makers usually find giving interval values to be more confident than fixed value judgments since the indefinite nature of comparison process makes them incapable to express their preferences.

In this respect, in the AHP literature alternative sets of 9-point scales that are mapped with verbal and graphical representation are developed. The most common four scales in the literature are as follows: Ma and Zheng (1991) pointed out that numerical values should correspond with verbal expressions, and proposed the use of 1/9, 2/9, . . . , 8/9, 9/9, 9/8, …, 9/2, 9/1 scale. Lootsma (1993) highlighted that the numerical counterparts should follow a geometric progression instead of arithmetic sequence of numbers as in Saaty (1980), and suggested the use of a geometric scale of 1, 2, $2^2$… Salo and Hamalainen (1997) pointed the importance of obtaining alternative balanced measurement scales and suggested a balanced scale of 1/9, 1/5.67, …, 1/1.22, 1/1, 1.22/1, …, 5.67/1, 9/1. Karlsson et al. (2007) argued the suitability of Saaty's (1980) 1-9 scale for expressing human views and converted this integer scale to a more convenient five-point scale of 1/5, 1/4, …, 1/2, 1, 2/1, …, 4/1, 5/1.

The AHP can be explained in four steps. The first step is a matrix (nxn) that is composed of rows and columns with the total number of requirements (n). The requirements should be inserted into the row and columns of this matrix. The second step is to perform pair-wise comparisons of all requirements according to the chosen criterion. For each pair of requirements the relative intensity of importance (See Table 4.1) should be assigned to the corresponding matrix cell (See Appendix A, Step 2). Each cell in the main diagonal of the matrix has the value of 1, since each requirement is paired by itself. For a matrix of order n, n(n-1)/ 2 comparisons are required. The third step is the normalization of the matrix (See Appendix A, Step 3). First the columns are normalized by dividing each element in the matrix by the sum of that column. Then, the rows are normalized by dividing each row sum with the number of requirements. As a result, the relative value of each requirement is assigned based on the estimated eigenvalues (See Appendix A, Step 4). The priority values are normalized elements of the eigenvector associated with the largest eigenvalue from the normalized matrix. The eigenvalue can either be computed manually or by using a computational medium that automates the calculation process.

Then, each eigenvalue has to be checked if it is consistent with the relative value of all requirements. The eigenvalues should be perfectly consistent with the relative value of all requirements. If the AHP ends with an inconsistency among requirements, the consistency index (CI) of the comparison matrix followed by the consistency ratio (CR) should be calculated. CI is the measure of consistency and effectiveness of the measurement that is determined with the maximum eigenvalue ($\lambda$max) number of requirements (n) (CI= $\lambda$max-n/n-1). CR is an indicator of the reliability of the resulting priorities and obtained by dividing CI by the random indices (for RI values see Appendix A). The value of CR, which is essential element for validating the success of the conducted AHP technique, should be about 0.1 or less with regard to an acceptable decision result. If it is greater than 0.10, the pair-wise comparisons results should be rejected and made again to improve the consistency and estimate an acceptable decision. Moreover, for an accurate, efficient and reliable AHP technique it is also advised that the compared requirements should be in the same level of abstraction with each other not to lead a false impression among decision makers (Lehtola and Kauppinen, 2006).

### 4.2.3 The Modified AHP Technique: A Cost-Value Approach

While prioritizing the requirements through pair-wise judgments, it is not enough only to calculate how many times one requirement is more important than another. Often there are also other factors and requirement interdependencies different than value, such as risk, benefit, time, opportunity and cost that influence decisions and affect the performance of the overall system. Thus, in the literature there are studies on the modified AHP techniques that are involved with the further developments of comparison matrix and priority values. One of the most well-known developments is the cost-value approach of Karlsson and Ryan (1997). They reviewed the basic ideas behind the AHP technique for prioritizing requirements. Based on these ideas they introduced the cost-value approach to guide designers more precisely in selecting the best decision (Karlsson and Ryan, 1997). In the cost-value approach, one determines the relative weight in percentage of each requirement according to its value and cost.

‘Value’ is defined as the quality regarding the contribution of each requirement to user satisfaction and corresponds how important the decision maker finds the requirement; whereas ‘cost’ is the required budget to implement each requirement and corresponds to how much the decision maker considers that the requirement adds cost to the overall design (Karlsson and Ryan; 1997). Having all requirements pair-wise compared first according to their value, and later according to their cost, cost-value graphs are drawn. To visualize the results and calculate three priority categories of requirements the cost value graph is divided into three areas as high, medium and low from the plotted graph (Figure 4.1).

$$\begin{cases} y/x \geq 2 & \text{if a requirement has high priority} \\ 0.5 \leq y/x < 2 & \text{if a requirement has medium priority} \\ y/x < 0.5 & \text{if a requirement has low priority} \end{cases}$$

where x: cost in percentage, y: value in percentage

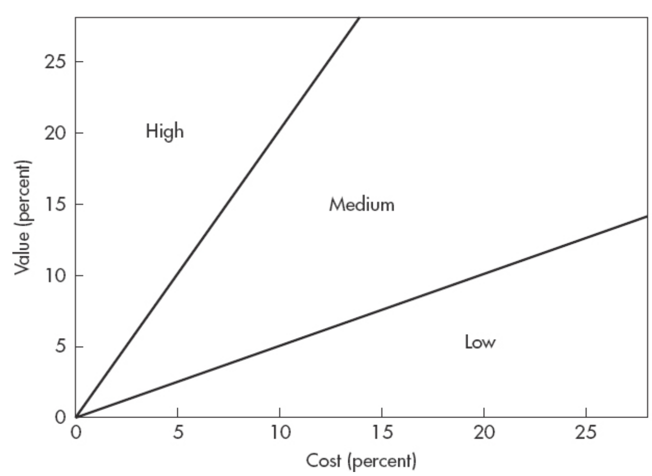


Figure 4.1. Cost-value graph (Karlsson and Ryan, 1997, p.68).

As illustrated in Figure 4.1, the upper line in the graph divides the requirements in a high ratio that have a cost-value ratio exceeding 2 and the lower line divides the requirements in a medium ratio that have a ratio between 0.5-2 from the requirements in a low ratio that have a ratio lower than 0.5 (Karlsson and Ryan, 1997). This graph is significant in terms of systematizing requirements which of them has the low cost-value ratio, i.e. low contribution to the system, and high cost-value ratio, i.e. high contribution to the system (Karlsson, et al, 2007). In this respect, the cost-value approach becomes essential to find the requirements that have high value but low cost.

## 4.3 Applying the Prioritization Techniques to the Universal Design Problem-Solving Process

The benefits and challenges both of the PG and AHP techniques are significant in terms of finding an appropriate prioritization technique that fits well into the universal design problem-solving process. The characteristic of the AHP technique is its flexibility to be combined with different techniques in different disciplines (Vaidya and Kumar, 2006). So, many outstanding works in various fields have been published based on different AHP applications that are combined with cost benefit, statistics, goal programming techniques to support the selection process of a most appropriate system/decision/requirement (Byun, 2001); with multi dimensional scaling, semantic differential and quality function deployment techniques to assess and evaluate the appropriateness of a system/decision/requirement (Fogliatto and Albin, 2001; Sarkis, 1999), with linear and goal programming techniques for planning and development facilities (Radasch and Kwak, 1998); with cognitive maps, cause and effect diagrams and tree diagrams to assist prioritization and ranking process (Bolloju, 2001); and with simulation techniques to solve decision making and handle uncertainty conditions (Hauser and Tadikamalla, 1996; Levary and Wan, 1999).

Although each of these combined AHP techniques helps successfully decision makers for the hierarchical structure of the AHP technique and systematic formulation of necessary calculations, they do not have contributed to the time-consumption and extensive work of pair-wise comparisons. The existing techniques take into account the ranking process only to a limited extent. Since in the AHP technique the number of ranked pairs grows quadratically with the number of requirements, decision makers find the ranking more time demanding that cause trouble and inaccuracies of judgments. In this respect, a more recent study by Karlsson et al. (2007) recommended that it could be valuable and worth of combining the AHP technique with the PG technique to conduct pair-wise comparisons having distributed the requirements into the three priority categories of the PG separately. “When the requirements have been ordered in a priority list using the PG it would be possible to compare each requirement to the one below it in the list and assign a number to their internal relation” (Karlsson et al., 2007, p.28). Then, the PG technique could be used with a ratio scale, whereas the AHP technique is applied with a reasonable amount of effort and manageable number of pairs.

Similar to software design and requirements engineering, the requirements in universal design process are also complex, volatile, vast and multi-faceted so that a manageable prioritization process, which can handle increasing number of requirements, is considered of a high importance (Ozkaya and Akin, 2006). The multi-parameter universal design requirements need to be both precisely and straightforwardly prioritized. Any universal design decision should include the careful consideration of the prioritized set of universal design requirements so that the assigned priorities have to be also checked for consistency and certainty. Thus, to achieve the challenges of the universal design problem-solving context this study proposes to use such a technique that is based on the hybridization of the two techniques: the PG and AHP using a cost-value approach. A universal kitchen design is chosen as a case study to apply the hybrid prioritization technique. The next section explains the overall structure of this technique in detail.

## 4.4 Overall Structure of the Hybrid Prioritization Technique for the Universal Kitchen Requirements

Figure 4.2 illustrates the overall structure of the hybrid prioritization technique considering the functionalities offered by the CAUD plug-in tool. Since the prioritized kitchen requirements are fed into the plug-in tool for supplying universal design evaluation of kitchen solution alternatives, time-consumption, ease of use, clarity, accuracy and consistency of the proposed technique become significant. Therefore, the choice of the used technique in each step of the prioritization procedure is done considering the fact that decision makers are seeking systematic, efficient and effective ways to prioritize requirements because of the limited time and budget resources of each design project (Lehtola et al., 2004). Practitioners want to get correct priority information and know what is truly important for users. So, the prioritization process should be trustworthy, fast and easy to manage rather than being overwhelming, inaccurate and inconsistent.

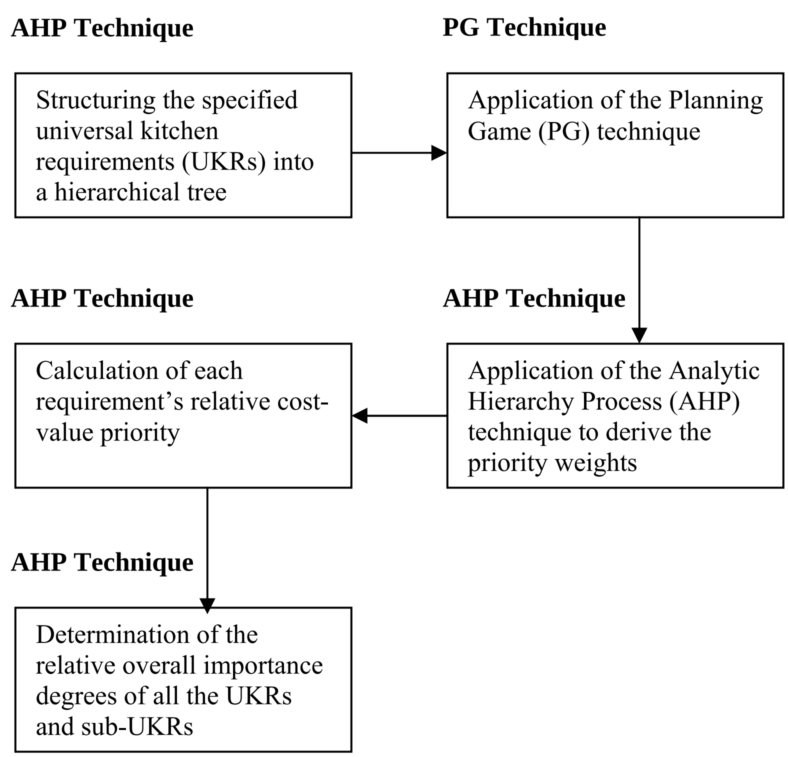


Figure 4.2. The overall structure of the hybrid prioritization technique.

The hybrid prioritization technique consists of the following five steps:

Step I. The universal kitchen requirements (UKRs), which are specified in relation to the changing kitchen demands of the diverse user needs (adults, elderly, physically disabled and visually disabled people), are structured into a hierarchical tree by using the AHP technique (Figure 4.3). Compared to single-level prioritization techniques, the hierarchical structure of the AHP technique allows better decomposition of complex problems so that the robustness of relative priorities among requirements is increased (Saaty, 1980). It allows to discuss the requirements much more objectively so that decision makers are not doubtful on the trustworthiness of the technique. This is due to the fact that the resulting importance degree of each requirement is relative that is based on a ratio scale and priorities always add up 100% (Saaty, 1980). So, the AHP technique enables versatile and deep analyses of a problem through the use of hierarchal trees. In the study, universal kitchen as the main goal is at the top of the hierarchy, followed by the UKR levels that contribute attaining the goal. At the bottom of each level there are also sub-levels of the UKRs.

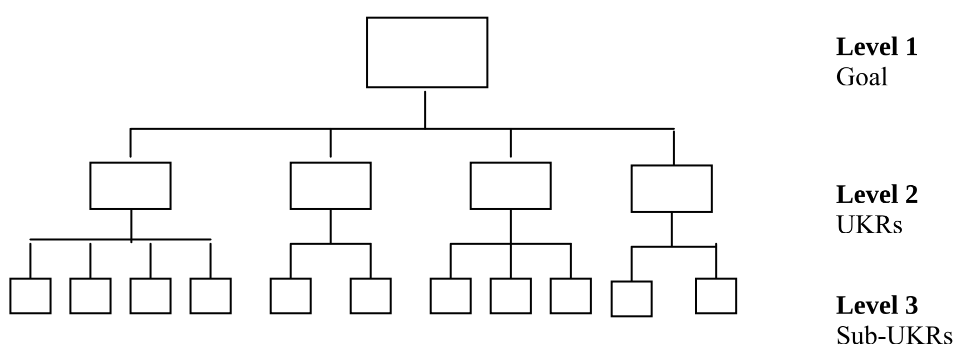


Figure 4.3. The hierarchical tree of the specified UKRs.

Step II. The PG technique is applied to the second hierarchical level (UKRs level) by the selected universal design specialists for the study, so that each UKR can be categorized as having high, medium or low priority (See Figure 4.4). The idea in utilizing the PG within an AHP framework is to evaluate UKRs within a short time easily and systematically, because the PG technique is found superior to the AHP technique in the experiments of Karlsson et al. (2007) with respect to time consumption and ease of use. Time consumption is the measure of the average time that is required by a decision maker to complete all stages of a prioritization technique, and ease of use is the measure that describes how easy is to use a prioritization technique (Karlsson et al., 1998). Both are dependent on the number of prioritized requirements. Karlsson et al. (2007) conducted two consecutive controlled experiments. In the first experiment, the PG was compared with the AHP and in the later with a tool-supported AHP in order to understand the differences in time consumption. The results of the experiments indicated that the total time that is needed for prioritization of the same number of requirements is longer while using the AHP technique compared to the PG.

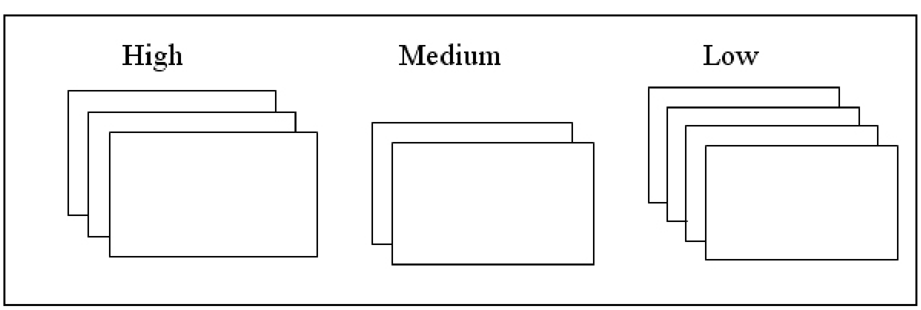


Figure 4.4. Example of the three PG category cards as high, medium and low.

The AHP technique becomes a more time demanding and complicated technique as the number of project requirements grows. Thus, pair-wise comparisons with over 20 requirements are difficult in practice (Karlsson et al., 2007). It is reported that after working more than half an hour, decision makers can become irritated and have difficulty to concentrate on the comparison process (Lehtola and Kauppinen, 2006). So, before applying the AHP in complex situations and large scale projects it would be helpful to make use of the PG technique. The PG technique can be regarded to be valuable in terms of decreasing the needed time and number of pair-wise comparisons by asking decision makers to answer how important a requirement is. Thus, practitioners have the opportunity to present the requirements in an ordinal scale and get an overview of the trade-offs among the requirements in the form of the PG categories. It helps decision makers to sense the depth of the kitchen problem before the pair-wise comparison and to give an indication of what requirements can be considered as having high, medium and low priority.

Step III. The AHP technique is applied to compare each requirement in the corresponding level (both UKRs and sub-UKRs) in each PG category. The use of AHP technique provides additional and detailed information, such as data on a ratio. This is a great potential for evaluating the multi-attribute problems as universal kitchen design process. Moreover, the mathematical basis of the AHP technique helps in differentiating precisely UKRs and sub-UKRs from each other where the overall results are depicted as numerical scores. Thus, this step is based on pair-wise comparisons that are made by the same universal design specialists in the previous step. Each specialist is required to fill the sheets for each UKR parameter within each pile by using 1-5 point scale, first according to value and later according to cost (See Figure 4.5 and Figure 4.6). The study modified the integer scale proposed by Saaty (1980) into a more convenient five-point scale because of the following two reasons: Firstly, according to Zhang and Nishimura (1996) using a 1-5 scale is better than using 1-9 scale at expressing human views and reducing the time required to handle inconsistency in decision making process. Secondly, most of the recent researches pointed out the weakness of the AHP technique regarding the clarity and understandability of its original 1-9 scale (Vaidya and Kumar, 2006). The weakness results from two limitations. First, using an importance scale of 1-9 scale makes difficult the decision makers in nominating the extent to which one requirement is more important than the other (Lehtola and Kauppinen, 2006). Second, there is also difficulty in identifying a requirement value considering the intermediate numbers between the two adjacent judgments. Selecting numbers from (1/9, 1/8, …, 1, …, 8/1, 9/1) contradicts with the real world situations. This weakness can cause extremely high failure rates in the AHP technique that can affect the results. Thus, for an effective use of the AHP, the choice of the right scale with its corresponding linguistic definition plays a key role in the accuracy and consistency of the prioritization process.

Which of the two requirements is more valuable to you?

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| R1 | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | R2 |
| R3 | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | R4 |

….

Figure 4.5. An exemplary pair-wise comparison sheet of 1-5 point scale for value.

Which of the two requirements costs more to you?

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| R1 | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | R2 |
| R3 | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | R4 |

….

Figure 4.6. An exemplary pair-wise comparison sheet of 1-5 point scale for cost.

Step IV. The paired comparison matrices are constructed both for value and cost and normalized separately to derive eigenvalues from the judgments of the specialists for each UKR and sub-UKR. The relative importance degrees of all requirements are calculated with respect to each other. Further, the study makes use of weight diagrams and cost-value diagrams based on the importance degrees, which are useful and informative in identifying the most important kitchen requirements necessary for a universal design implementation within a kitchen system that costs as little as possible. These diagrams are constructed to calculate the right amount of effort that should be spent on each of the UKRs.

Step V. The relative overall importance degrees and global weights of all UKRs and sub-UKRs are determined. The global weight of a UKR or sub-UKR is the importance, when all requirements are considered jointly regarding their cost-value ratio. Moreover, the AHP technique plays crucial in verifying the consistency of each importance degrees and calculating the CR and CI so that kitchen practitioners can be informed whether there are any judgments errors of the pair-wise comparisons during the AHP process. Since in practice, human decision making process is subject to the inconsistency of the judge so that consistency check and examinations based on consistency become essential for the accuracy of the estimated priorities (Leskinen, 2000). Especially, the AHP technique, where decision makers usually give some or all pair-wise comparison values with a certain degree of uncertainty rather than precision, is insensitive to judgmental errors due to redundancy of pair-wise comparisons (Karlsson et al., 2007). Thus, compared to the PG technique, this technique includes consistency check to indicate the consistency in judgments. The detailed explanations of each step can be found in the next chapter that explains the development of the CAUD plug-in tool taking into consideration the hybrid prioritization technique described above.

# 5. DEVELOPMENT AND IMPLEMENTATION OF THE CAUD PLUG-IN TOOL FOR A UNIVERSAL KITCHEN DESIGN

The CAUD plug-in tool is developed in order to assist designers in creating universal design solutions successfully beginning from the conceptual design phases. In the study, universal kitchen design is chosen as a case design. Universal kitchen is an inclusive approach to kitchen design that is designed to allow full participation of all people regardless of age, ability and size (Young and Pace, 2001). Creating a promising universal kitchen is a many-faceted design process (Universal Kitchen Design Course, 2007). The designer is responsible for exploring the correlations between user needs and design specifications. While able-bodied users experience minimal difficulties, children, pregnant women, elderly, people with physical, visual and hearing disabilities and seated users face diverse challenges regarding the kitchen layouts, gaining access to cabinets and storage areas, reaching counters, using appliances and operating controls (Mullick and Levine, 2001). However, for a kitchen to be universal it should accommodate all the needs and offer diversity, usability, adaptability and adjustability within the same system.

The schematic representation of the procedure for the development of the CAUD plug-in tool is illustrated in Figure 5.1. It consists of three main stages. The first stage is concerned with elicitation of diverse kitchen user needs to identify the UKRs with the related sub-UKRs. This stage conducted with 135 Turkish kitchen users. In the second stage, the hybridization of the PG technique and AHP technique using a cost-value approach is carried out with 9 universal design specialists to prioritize the UKRs and sub-UKRs. The final stage is the incorporation of the derived priorities into a CAD environment, SketchUp software. It is achieved through Ruby API within the SketchUp environment. The primary goal of this stage is to provide an integrated CAD medium, where designers can be informed about the cost-value ratios of each UKR and sub-UKR in the analysis, synthesis and evaluation operations while producing universal kitchen design solutions. The next sections of the study explain each stage in detail.

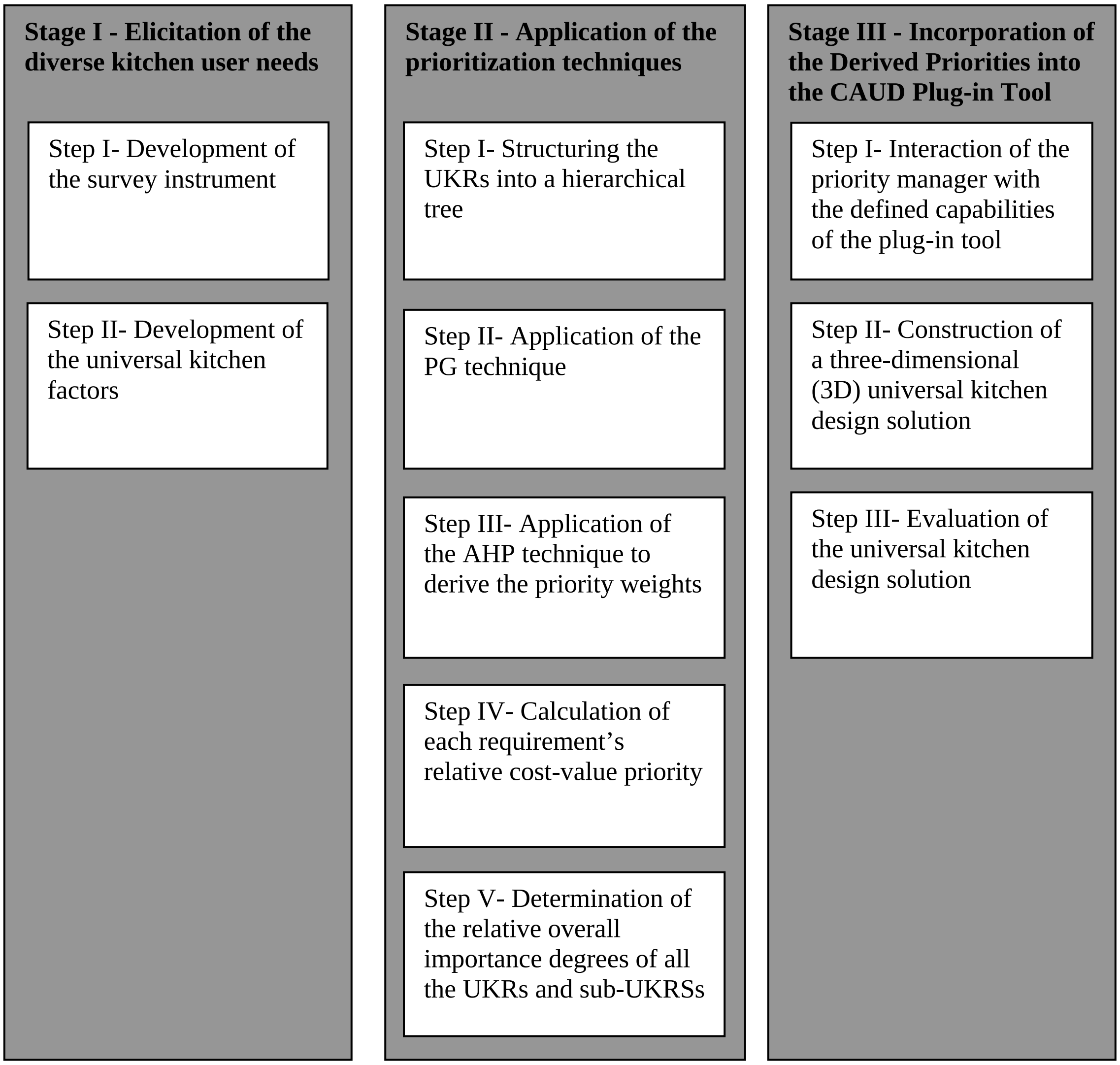


Figure 5.1. The procedure for the development of the CAUD plug-in tool.

## 5.1 Stage I: Elicitation of the Diverse Kitchen User Needs

This stage deals with gaining a better understanding of user needs, on which a successful universal design is typically built. The process of elicitating user needs can be defined as discovering what the user needs are that should be addressed during the design process. Since the abilities of users change in the course of time, a kitchen should be designed as efficient, effective and satisfactory as possible regardless of user's health condition, body size, strength, experience, mobility power and age. While using the kitchen, users also want to spend low physical effort and have security, safety and simplicity in use. However, every changing need results in an increase in cost that is in terms of money, time, and effort. Therefore, providing a systematic approach for a cost-effective universal kitchen design is highly related with the elicitation of user needs at first. Designers should be informed about the kitchen user needs as early as possible during the design process in order to achieve all these challenges and to ensure that an ideal kitchen design is addressed.

Elicitation should involve the environment where the interaction of user with the potential product occurs, in order to achieve user's goals. The ability to capture user needs correctly is essential to reduce the late discovery and to increase the user satisfaction (Arthur and Gröner, 2005). However, universal design literature lacks systematic procedures and methods in identifying and expressing user needs within the interior spaces. Although there are guidelines and accessibility standards, designers have difficulty in reading and sorting this academic source of information (Gregor et al., 2005). Moreover, most of the user information is presented in textual and numerical form so that it needs interpretation when incorporated into a design project (Carmichael et al., 2007). In order to overcome these elicitation inadequacies in universal design process, this stage is composed of two steps. At first, a survey instrument is developed, which is based on a user-centered approach and provides an accurate basis for the elicitation of diverse user needs while discovering, how they are correlated with each other. Secondly, statistical analyses are conducted to refine the survey instrument and evaluate the survey data. Based on the exploratory factor analyses, universal design factor scales that characterize UKRs are constructed.

### 5.1.1 Development of the Survey Instrument

A survey instrument with a comprehensive list of 87 items is developed to gather information on the evaluation of the participants' kitchen environment (Appendix B). The survey instrument includes kitchen design features that contribute or can be components of a promising universal kitchen solution. It is based on a structured questionnaire format with close-ended questions covering various aspects of a kitchen that can be used by everyone regardless of the level of ability or disability. The eighty-seven items were comprised of both international universal design and human factors design resources presented in the literature. Each item was retrieved from the descriptions of the existing kitchen design guidelines, affordable design practices, universal design principles, technical specifications, comments and dimensional standards (Barrier free environments Inc., 1991; Canadian Human Rights Commission, 2006; The Center for Universal Design 1997; 2007a; 2007b; Goldsmith, 1997; Grist et al., 1996; Mullick and Levine, 2001; Young and Pace, 2001). During the survey, the users were asked to rate their importance level for each item on a scale of 1-5, (1 being the least important and 5 the most important) and to mark the appropriate boxes to identify how important is each of the following features in working successfully within a kitchen environment. The items were grouped under eight categories on the basis of essential requirements for daily kitchen activities: (1) circulation; (2) cabinets and storage areas; (3) work surfaces/counters; (4) appliances; (5) sink and faucet; (6) controls, such as receptacles, switches; (7) illumination; and (8) materials.

#### 5.1.1.1 The Sample Group

A total of 135 kitchen users participated in the survey, including 45 adults (age less than 65), 45 elderly (age 65 and more) and 45 disabled adults including 25 physically disabled who use wheelchairs (n=13), crutches (n=7), prostheses (n=3) and canes (n=2) as mobility aids, and 20 visually disabled adults having total loss of sight (n=8) and mild loss of sight (n=12). The demographics of the participants are shown in Table 5.1. The age range of group of adults is between 28 and 58 years and elderly between 65-97 years. The physically disabled participants, whose age range is between 28-51 years, were selected from the existing database of the Federation of the Physically Handicapped of Turkey and Turkish Handicap Association. The visually disabled participants, whose age range was between 30-59 years, were randomly selected from the existing database of the Federation of the Blind of Turkey and ‘Alti Nokta’ Blind Foundation.

Table 5.1. Demographic characteristics of the participants

| **User Group** | **Adults** | | **Elderly** | | **People with disabilities**<br>**Physical** | | **Visual** | |
|---|---|---|---|---|---|---|---|---|
| | **F** | **M** | **F** | **M** | **F** | **M** | **F** | **M** |
| **Number of participants** | 28 | 17 | 29 | 16 | 13 | 12 | 10 | 10 |
| **Age** | 28-57 | 30-58 | 65-97 | 66-90 | 28-51 | 32-49 | 30-55 | 28-59 |
| **Disability status** | - | - | - | - | Using wheelchair (n=6)<br>Using crutch (n=4)<br>Using prosthesis (n=2)<br>Using cane (n=1) | Using wheelchair (n=7)<br>Using crutch (n=3)<br>Using prosthesis (n=1)<br>Using cane (n=1) | No vision (n=4)<br><br>Low vision (n=6) | No vision (n=4)<br><br>Low vision (n=6) |

### 5.1.1.2 The Procedure

The data were collected during face-to-face surveys with all the participants. At the beginning, a brief summary of the procedure and the aim of the study were explained. The participants were informed that the questions related to a kitchen environment in the survey should be responded according to how important they found each kitchen statement for an ideal kitchen. During the survey with 20 visually disabled participants and with some frail elderly, who experienced age-related difficulties, the experimenter helped them in reading the survey items and asking to rate each item in order to mark their responses. Throughout the survey, the meanings of some terms such as ‘colour contrast’, ‘work triangle’ and ‘pull-out shelves’ were made clear for participants to avoid any misunderstanding. The survey lasted from 60 to 75 minutes for each participant. Moreover, during the survey an unstructured interview was also conducted with each participant, which helped in the discussion of the results in a more comprehensive way. Furthermore, to avoid any biases participants were not allowed to listen to others while they were surveyed.

#### 5.1.1.3 Refinement of the Survey Instrument

The study identified the uninformative and irrelevant survey items among 87 kitchen items regarding the responses of 135 participants. To carry out an effective data analysis, the items were eliminated based on two refinement factors: (a) floor and/or ceiling effects and (b) the strength of correlation scores. A floor and/or ceiling effect can be occurred if response means for each item are lower and/or higher than they should be (Krathwohl, 1997), i.e. they are at the extreme ends of the used scale. In the study, the participants' responses were coded using 1-5 scale: (1) 'Least important', (2) 'Less important', (3) 'Moderately important', (4) 'More important' and (5) 'Most important'. So, the items with a mean score lower than 1.50 and greater than 4.50 were deleted to eliminate the floor and ceiling effect. The frequency analysis of the survey indicated that the survey item 13, 70, 72, 75 and 77 have mean scores of 1.20, 1.17, 1.40, 1.40 and 1.36, respectively. Thus, these five statements were excluded from additional data analyses. There were no means scores greater than 4.50 so that no items with a ceiling effect were excluded.

The strength of the correlations among the survey items were calculated through the exploratory factor analysis. Factor analysis helps to identify common issues of items and get rid of any unrelated ones. Pearson product-moment correlations of the response scores were calculated and a correlation matrix was constructed to investigate response items having a correlation score lower than 0.30, because for a useful statistical approach a correlation coefficient of 1.00 indicates a perfect association between two variables, whereas correlation coefficients lowers than 0.30 are not preferred (Argyrous, 2005). However, in the study all of the correlations between item response scores were greater than 0.30. Finally, total of five items were found irrelevant and uninformative regarding the three refinement factors and eliminated.

### 5.1.2 Development of the Universal Kitchen Factors

The ratings of the participants on 82 items were analyzed by using the Statistical Package for the Social Sciences (SPSS). First, exploratory factor analysis was used to carry out data analysis. By using the Varimax method, which is a most frequently used rotation option (Argyrous, 2005), a rotated component matrix was constructed to identify the number of potentially interpretable factors among the set of correlations within the obtained data. The matrix indicated the extracted factors with their factor loadings. The factor loading of each item was a critical determination value, which provided an estimate of which of the 82 items were highly correlated to a respective factor and therefore, should be included in the interpretation of factor analysis results (Argyrous, 2005). Based on Hogarty et al.'s (2005) experiments, the study defined factor loadings in excess of 0.71 were excellent and excluded factors with factor loading values below 0.71. Moreover, the study also removed the factors including less than three items to avoid a poor correlation structure. In this respect, the factor analysis resulted in a 6-factor solution that accounted for 64.048% variances, i.e. 82 items have 64.048% variances in common, so that they correlated highly with 6 common themes and each theme was considered as a factor scale (Table 5.2). Since a factor is usually identified according to the item with the highest factor loading (Argyrous, 2005), the names were given to the 6 factors regarding the items with the highest loading values of each factor. Appendix C gives the detailed list of the 6 factors with their corresponding items and the factor loadings for each item under each factor.

Table 5.2. Summary of rotated factors.

| **Factor** | **Scale** | **Eigenvalue** | **Variance (%)** | **Cumulative (%)** |
|---|---|---|---|---|
| 1 | Operation of controls with less force | 17.765 | 21.665 | 21.665 |
| 2 | Appropriate counter heights and spaces | 15.788 | 19.253 | 40.918 |
| 3 | Operation of controls with perceptible information | 10.440 | 12.731 | 53.649 |
| 4 | Adequate illumination | 4.029 | 4.913 | 58.562 |
| 5 | Ease of reach to oven | 2.282 | 2.783 | 61.345 |
| 6 | Ease of reach to base cabinets | 2.216 | 2.703 | 64.048 |

#### 5.1.2.1 The Six Universal Kitchen Factor Scales

These six factor scales were also derived regarding their correspondence of seven universal design principles (Principle 1: Equitable use; Principle 2: Flexibility in use; Principle 3: Simple and intuitive use; Principle 4: Perceptible Information; Principle 5: Tolerance for error; Principle 6: Low physical effort; Principle 7: Size and space for approach and use, See Appendix D for their detailed description). In this respect, the scales were developed by taking into account that a scale has embraced more than one universal design principle. Factor 1 and 3 deal with the operation of controls with low physical effort and perceptible information, respectively. By low physical effort, the study referred that all of the controls including receptacles, appliance controls, faucet and door handles could be operated comfortably by everyone who is weak or tired. They can be also used without repeating any motion enough to cause fatigue or pain. Moreover, the simplicity in operating controls is important as well as their use with less force. Operation should be simple and straightforward so that an untrained kitchen user can operate the controls and access the most important features of controls easily (The Center for Universal Design, 2007a; 2007b). By perceptible information, the study referred to providing pictorial, verbal and tactile cues consistent with user intuition. Controls should have adequate illumination levels, visual and audible cues for easy and safe operation. At controls the legibility of essential information should be maximized for people with sensory limitations to reduce errors and hazards (Canadian Human Rights Commission, 2006). The controls should be made appealing to all users and provide safe means of use regardless of user experience and knowledge. In this respect, the universal kitchen should ensure that the controls comply with people's limits and enhance their operating capacities to sense, communicate, and act with diverse type of kitchen users. Architects should choose appliances with control devices that are equipped with simple intelligence and warn users of hazards and provide timely advice by sounding, lighting and multiple methods of interpreting information.

Factor 2 is related with installing the counters at a comfortable and accessible height so that everyone can use the counter without any abnormal stretching and changing the neutral body position. Addressing the height, area and material to be used are the main concerns when designing counters in the universal kitchen (Universal Kitchen Design Course, 2007). Both counter heights and spaces should not cause physical strain. Since the counter is an integral component of the food preparation, baking, beverage, and clean-up (Goldsmith, 1997; Grist et al., 1996) appropriate counter spaces should be designed that remain within a safe distance without any accidents. For people who must sit while performing counter facilities, there should be necessary pull-out work surfaces to allow them to pull up under the work surface and sit close enough to work.

Factor 4 deals with the adequate illumination levels for both maximizing legibility of essential information at working surfaces for people with sensory limitations and assisting every user with reduced visual and cognitive function to reduce errors and hazards at cook-top. When planning universal kitchen, care and attention should be paid to the amount of both natural and artificial light. Key to maximizing the function and enjoyment of the universal kitchen is the quality of light for all users, not only for people with aging vision and visual impairments (Universal Kitchen Design Course, 2007). Adequate illumination levels are required to insure that each function occurs in the kitchen can be accomplished by diverse type of users efficiently and safely.

Factor 5 is related with ease of reach to the oven even from a wheelchair. Ovens should be located at accessible heights for people with limited ability to reduce reach distances to use them comfortably. Moreover, there should be also an appropriate counter space at least one side of the oven to manipulate hot pots and pans easily because creative planning of surrounding countertops could maximize the safety and use of the oven (Universal Kitchen Design Course, 2007). Furthermore, clear floor space should be provided for wheelchair users to maneuver close enough for either parallel or perpendicular approach. In this respect, a wall or countertop oven with a side-swing door could be a better choice for a universal kitchen that minimizes to need to bend, lift or carry hot pots (Barrier free environments Inc., 1991). There can be also temporary landing surfaces, such as rolling carts that act as a safe transfer for hot pot and pans. The location of the oven to other appliances, work surfaces, knee space and height are the components for ease of reach to the oven.

Factor 6 deals with both forward and parallel reach to base cabinets including corner cabinets. Because of limited reach ranges, both the rear and low portions of the base cabinets are unusable for mobility impaired people. “Many people are able to reach at least the lower level of shelves of conventional wall cabinets, but because of limited ability to bend over or stop down, they may be unable to use low and/or rear portions of base cabinet storage” (Barrier free environments Inc., 1991, p.112). In this respect, this factor is concerned with the ease of use base cabinets for a universal kitchen. There should be alternative storage options to compensate for the limited reach ranges and allow features to be used by both standing and seated users, such as rotating or sliding cabinet shelves. Moreover, insuring ease of access and use without deep bending is essential to maximize storage capacity within reach in the blind corner base cabinets. In this respect, rotating mechanisms/ lazy-susan units/moon swing-out shelves can be placed in corner base cabinets for effectiveness and efficiency. By effectiveness, the study referred to a condition of usage that all users see and reach the contents within the cabinets without bending over awkwardly. By efficiency, it is meant to best exploit the storage space through rotating and pull-out mechanisms. Backside storage items should be easily identified and accessed with a minimum effort (Universal Design Course, 2007). Overall, regarding the usage of base cabinets, maximizing storage capacity within reach and minimizing movement from one area to another when lifting is essential.

#### 5.1.2.2 Kitchen Need Differences between the User Groups

The study utilized ANOVA on each factor scale score and calculated the F-ratio in order to analyze whether the scale means of the user groups were significantly different from each other. Since the F-test itself does not indicate which of the user groups differs with respect to the corresponding scale (Argyrous, 2006), the study continued the ANOVA analyses with Bonferroni post hoc comparisons if F-test discovered any statistically significant difference between the user groups. Except factor 4, 'Adequate illumination', whose means between the four users groups were close to each other (F=2.593, df=(3, 12), p=0.320), the study found statistically significant differences between the user groups in the five factor score scales. With regard to factor 4, all participants considered both general lighting (items 79 and 80) and task lighting (items 81 and 82) to be more important (means for 4 items=3.99; 4.05; 4.33; and 4.27 respectively).

For factor 1, the 'Operation of controls with less force', the between groups effect was statistically significant (F=283.798, df=(3, 44), p<0.01). Elderly participants differed significantly from the rest of the group (See Table 5.3). Due to the aging process, the elderly users experience difficulties in their physical abilities and tasks that require more physical effort and cause fatigue. They prefer to use the kitchen control features with less force and without having to repeat any motion enough to cause pain while operating them. Moreover, because of a decline in their cognitive abilities, most of the elderly participants, 40 of 45, found the simplicity issue in operating the controls more important (for items 44, 55, 60 and 65 with means=4.12, 4.69, 3.72 and 4.05 respectively). The response means of the physically disabled participants were close to the visually disabled participants regarding the 12 items of factor 1. Both disabled participants indicated that they found operating the controls with less force and simplicity less important (mean of the physically disabled participants for 12 items= 2.16 and mean of the visually disabled participants for 12 items= 2.03). However, different than the visually disabled participants most of the physically disabled participants, 22 of 25, found item 45 and 62 more important (means=4.00 and 4.23 respectively), whereas most of the visually participants found item 53 more important (mean=4.67).

Table 5.3. Mean scores and standard deviations for factor 1

| **User Group** | **Mean** | **Standard Deviation** |
|---|---|---|
| Adults | 62.66 | 12.98 |
| Elderly | 177.42 | 18.66 |
| People with physical disabilities | 38.08 | 9.33 |
| People with visual disabilities | 38.58 | 11.98 |

The mean scores of factor 2, the ‘Appropriate counter heights and spaces’, indicated that there was a statistically significant difference between the user groups (F=5.732, df=(3, 24), p=0.04, See Table 5.4). Compared to the adults and elderly, the disability status of the participants affected the importance level of the counter height and spaces. Although the response means of adult and elderly participants indicated that they considered items 17, 18 and 19 to be less important (means= 1.00; 1.09 and 1.33

respectively), both physically and visually disabled users found these three items more important (mean=4.04; 4.08 and 4.10) to be able to work with maximum efficiency. Moreover, all of the visually disabled participants emphasized the importance of a heat resistant counter material (mean=4.80 and 4.67 respectively) because visually disabled users use their hands to touch and sense while they are working on the counters and physically disabled participant make use of the counter surface to be able to stand in a balanced manner. Therefore, the surface of the counter should be without burn marks, impervious to the thermal shocks of hot foods and should not blister if a hot pan is put down on it (Canadian Human Rights Commission, 2006). Furthermore, all users regardless of their ability or disability found an appropriate counter space on each side of cooking surface and sink as the most important feature with respect to counter usage (mean=4.95 and 4.86 respectively).

Table 5.4. Mean scores and standard deviations for factor 2

| **User Group** | **Mean** | **Standard Deviation** |
|---|---|---|
| Adults | 124.43 | 34.21 |
| Elderly | 129.43 | 61.00 |
| People with physical disabilities | 82.86 | 13.29 |
| People with visual disabilities | 54.14 | 26.49 |

Factor 3, the ‘Operation of controls with perceptible information’, means differed statistically significant between the user groups (F=15.357, df=(3, 80), p<0.01). Compared to the adults, elderly and physically disabled participants’ responses, visually disabled user group’s responses differ significantly (Table 5.5). Most of the visually disabled people, 18 of 20, emphasized the importance of operating the controls with perceptible information (mean of the visually disabled participants for 8 items=4.11). Since the controls did not provide any compatibility with a variety of techniques, such as color-contrasts, braille markings, large-print readouts, audible and tactile feedbacks, 16 of 20 participants with visual limitations had difficulties to know where and how the controls were set so that all of the visually disabled participants found provision of helpful feedbacks by cook-top controls as the most important item of factor 3. Moreover, because of the experienced visual difficulties and limitations due to the aging process, elderly mean scores were closer to the ones of the visually disabled people. Most of the elderly participants with low vision, 35 of 45, can experience difficulty performing everyday tasks, such as reading text on appliances, or recognizing warning features so that low vision increases hazards and risks and threatening independent living. Therefore, elderly participants, 42 of 45, emphasized the safe usage of appliances and indicated that it would be helpful if the appliances give them helpful feedbacks, warn about potential hazards and prompt them to pay attention during a hazardous action.

Table 5.5. Mean scores and standard deviations for factor 3

| **User Group** | **Mean** | **Standard Deviation** |
|---|---|---|
| Adults | 80.50 | 39.35 |
| Elderly | 94.13 | 49.33 |
| People with physical disabilities | 51.63 | 29.51 |
| People with visual disabilities | 103.12 | 2.47 |

The F-test results of factor 5, the ‘Ease of reach to oven’, indicated that there existed significant differences between the physically disabled participants and the rest of the groups (F= 31.739, df=(3, 8), p<0.01, Table 5.6). The physical disability status of a participant significantly affected her/his importance rating to the items of factor 5. Since for wheelchairs users the drop-front oven doors gets in the way of maneuvering one’s chair and restricting reach into the oven and for people with crutches and canes pulling close enough to the ovens and manipulating pots difficult (Mullick and Levine, 2001; Young and Pace, 2001), most of the physically disabled participants, 23 of 25, found ease of reach to the oven and close approach to the oven as the most important features (mean=4.67 and 4.76 respectively). The oven should allow both comfortable side and forward reach. Moreover, all of the visually disabled participants considered an appropriate counter space at least on one side of the oven at the same level as the rack to be more important (mean=4.05). As low vision increases fall risk, hot pots and pans should be placed temporarily on a counter space after they are removed from ovens (Barrier free environments Inc., 1991).

Table 5.6. Mean scores and standard deviations for factor 5

| **User Group** | **Mean** | **Standard Deviation** |
|---|---|---|
| Adults | 109.66 | 6.11 |
| Elderly | 142.00 | 9.16 |
| People with physical disabilities | 60.66 | 9.86 |
| People with visual disabilities | 46.33 | 19.63 |

For factor 6, the ‘Ease of reach to base cabinets’, the between groups effect was statistically significant (F=217, 741, df=(3, 8), p<0.01). Although both physically and visually disabled participants did not differ between them, there was a statistically significant difference between the adults and elderly and adults and all disabled participants (Table 5.7). The mean values of adult participants indicated that most of them found ease reach of the base cabinets moderately important, whereas disabled participants and elderly considered the three items of factor 6, items 7, 9 and 12, to be more important. While most of the adults, 35 of 45, reported that they could easily reach to the low levels of all base cabinets, all of the elderly participants had reach limitations due to the aging process so that 33 of 45 elderly participants found ease of use of the rear portions of base cabinets as the most important feature. For wheelchair participants and participants with crutches and canes bending over and lifting a kitchen object from an unreachable base cabinet were also difficult. Furthermore, vision loss affected negatively on usage of base cabinets. So, most of the visually disabled participants, 16 of 20, experienced difficulties to see easily all the contents within the base cabinets.

Table 5.7. Mean scores and standard deviations for factor 6

| **User Group** | **Mean** | **Standard Deviation** |
|---|---|---|
| Adults | 128.67 | 1.15 |
| Elderly | 199.00 | 4.58 |
| People with physical disabilities | 108.67 | 6.35 |
| People with visual disabilities | 91.33 | 10.97 |

### 5.1.3 Discussion

These six factor scales can be defined as the universal kitchen requirements (UKRs) and their corresponding items as the sub-UKRs. Having analyzed the survey results, it is possible to discuss them further under two issues. First is the parametric characteristic of the UKRs, and second is the correlation difference of the requirements in terms of the diverse user groups. The presentation of the six universal design factor scales in the set of parameter correlations indicated that achieving a successful universal kitchen design solution necessitates the consideration of each UKR with its sub-UKRs simultaneously. It is not adequate to respond to a selective set of requirements in order to satisfy the diverse needs of users. For example, the requirement of 'Adequate illumination' is correlated with its four sub-UKRs. Therefore, it is not possible to ensure an adequately illuminated kitchen by only providing adequate natural and artificial light. Since it also depends on task lighting above the counters and cook-top, where the legibility and visibility is required. Since the lighting is closely intertwined with the electrical receptacles and switches, which is the correlated sub-UKR of the 'Operation of controls with less force' requirement, there is a parametric relationship between illumination requirement and operation of controls that act as constraints on a universal kitchen design. In order to use the oven easily, at least five parameters should be applied. Besides the provision of the clear floor space for access and comfortable operation its controls, there should be also an appropriate counter space on both sides for its ease of use. Moreover, the designer should also consider a group of requirements simultaneously for a successful universal kitchen performance and improved functionality. Since the ease of use of the oven is closely intertwined with both the operability of the controls and ease of reach, there is a direct parametric relationship among factor 1, factor 3 and factor 5 that act as the primary constraints on a universal kitchen design. Besides the provision of the clear floor space for access and reach to oven, there should be also provision of helpful feedbacks, availability of warning features, simplicity and low physical effort for comfortable, easy and safe operation of its controls. In this respect, more than one requirement should be evaluated simultaneously or procedurally. Therefore, focusing on the representation, solution and optimization of the parametric universal kitchen constraints is as important as elicitating, capturing and describing UKRs.

The second issue is the significant differences between the user groups with respect to each factor. Both the physical and visual disability of a user can affect the design process of a kitchen. A universal kitchen should provide access to people with mobility aids to maneuver close enough to cabinets and appliances for reaching the door handles and operating controls, and also accommodating simple, audible, tactile and braille features consistent with the expectations and intuition of the visually disabled people to maximize ease of use, legibility and safety. Compared to the other user groups, the clear floor spaces can not be convenient and adequate for physically disabled users. Thus, additional maneuvering spaces that are consistent with the adjustability and affordability concepts should be included in the universal kitchen design. As stated in the literature, the survey results also found that visually disabled users require visible storages, illuminated controls, audio-visual warnings, rounded counter edges and color-contrasted materials to enable a participant with low vision to see something on the floor and counter more readily. In this respect, modifications needed in kitchens are usually less structural for the visually disabled users than the users with mobility aids.

As stated in the results, the kitchen requirements for non-disabled and disabled users are in conflict. However, in some cases, such as factor 1 and factor 3, operation of controls with less force and perceptible information, due to the aging process, elderly experience physical and/or visual limitations so that their ability to interact comfortably with a kitchen environment is impaired. Therefore, similar to the disabled users they need an increased functionality and usability within their kitchens. Although there were significant differences between the user groups with respect to the stated factors, a universal kitchen should be accessible, usable, intuitive and comfortable to both non-disabled and disabled users and accommodate their diverse needs. In this respect, there are questions regarding the importance degree of each requirement. Even with the developed universal design factor scales, creating a universal kitchen can still be a very complex and time-consuming activity. Since the factor loading of each UKR does not tell the importance degree, these UKRs should be prioritized to assist designers in deciding, which of the requirement is relatively more important than the other and thus, should be implemented first. Therefore, the next sub-sections deal with the proposed prioritization technique as the second stage of the procedure to overcome the complexity and effort required for designing a universal kitchen.

## 5.2 Stage II: Application of the prioritization techniques

During the second stage, the hybrid prioritization technique, the PG technique and AHP technique using a cost-value approach, was applied. This stage is composed of the five steps. Each step is elaborated below.

### 5.2.1 Structuring the UKRs into a Hierarchical Tree

This part is related to the AHP technique that is used for assessing the priority weights to the six factor scales of a universal kitchen. Since the strength of the AHP lies in its ability to structure complex and multi-attribute problems (Saaty, 1980), the study uses this technique in structuring the universal kitchen hierarchy by representing the derived six factor scales in a hierarchical form. This hierarchy is depicted in Figure 5.2 as a tree diagram. The tree structure of the universal kitchen design problem involves a three level of hierarchy- a goal, a set of criteria and sub-criteria (Saaty, 1980). Designing a universal kitchen as a main goal is at the top of hierarchy; the UKRs in the second level are the six factor scales; and at the bottom of each UKR there are also sub-UKRs. The sub-UKRs are the corresponding items of each factor scale: under factor 1 “Operation of controls with less force” there are eleven sub-UKRs; under factor 2 “Appropriate counter heights and spaces” seven sub-UKRs; under factor 3 “Operation of controls with perceptible information” eight sub-UKRs; under factor 4 “Adequate illumination” four sub-UKRs; under factor 5 “Ease of reach to oven” three sub-UKRs and under factor 6 also three sub-UKRs. The use of such a hierarchical tree in the study enables versatile and deep analyses of the kitchen problem. The next section of the study is concerned with the application the PG technique.

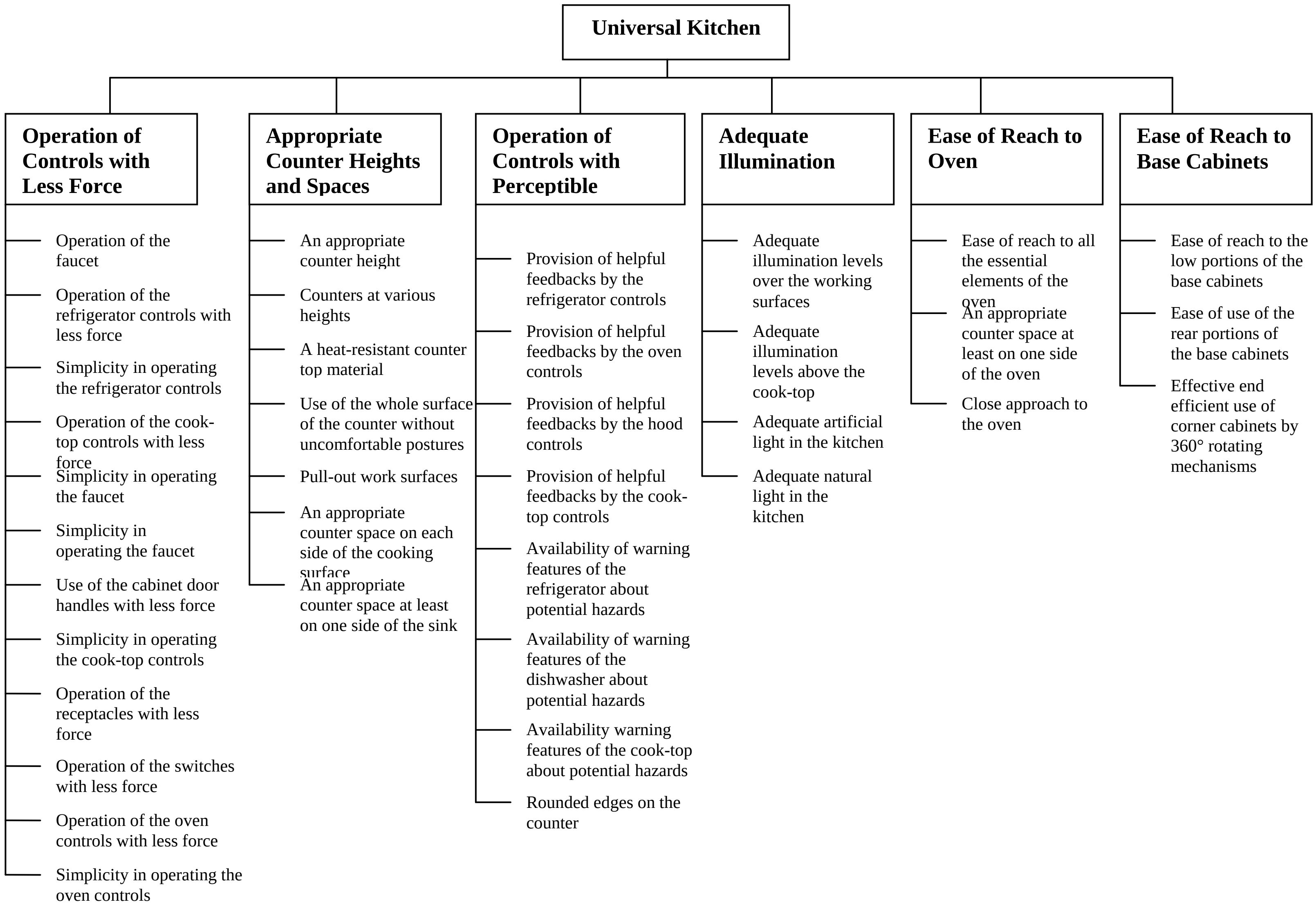


Figure 5.2. The hierarchical tree structure of the universal kitchen design problem

### 5.2.2 Application of the Planning Game (PG) Technique

Having the hierarchical structure of the universal kitchen been identified based on the survey results, the Planning Game (PG) technique is applied for each UKR in the second level of hierarchy. Before applying the AHP technique, the PG in the study can be regarded to be valuable in terms of decreasing the needed time and number of pair-wise comparisons. It helps the designers to sense the depth of the kitchen problem before the pair-wise comparisons and to give an overall indication of which UKR can be considered as having high, medium and low priority.

#### 5.2.2.1 The Procedure

The PG technique was carried out with nine universal design specialists from different design disciplines; namely, three industrial designers, three interior architects and three architects. These specialists are academicians, who teach universal design courses and deal with the universal design issues in both their academic and professional life. Before the PG began, a summary of the study was provided to each specialist and a short introduction on how to perform the two prioritization techniques, the PG and AHP, were given briefly. It was also explained that the UKRs and sub-UKRs used in the prioritization techniques were universal kitchen features, which were obtained from the statistical analyses of the survey results that was conducted with the 135 diverse kitchen users. The prioritization was performed individually and guided by the author. Each specialist was asked to prioritize the six UKRs into the three PG categories as high, medium and low (See Appendix E for the PG cards). In each prioritization process, a different order of factor scales was used in order to eliminate order effects. While categorizing, the author also required from the specialists to think aloud in order to elicit a more detailed prioritization process.

#### 5.2.2.2 Findings

Each universal design specialist carefully reviewed the UKRs and distributed them into the three categories of the PG. To calculate the corresponding category for each UKR, the mean values of the distributions by the nine specialists was determined. In average, the specialists distributed an equal number of UKRs into each category. Figure 5.3 illustrates the resulting PG categories. High category included the two UKRs: the ‘Appropriate counter heights and spaces’ and the ‘Operation of controls with perceptible information’; the medium category the two UKRs: the ‘Adequate illumination’ and the ‘Ease of Reach to Oven’ and the low category the two UKRs: the ‘Operation of controls with less force’ and the ‘Ease of reach to base cabinets’.

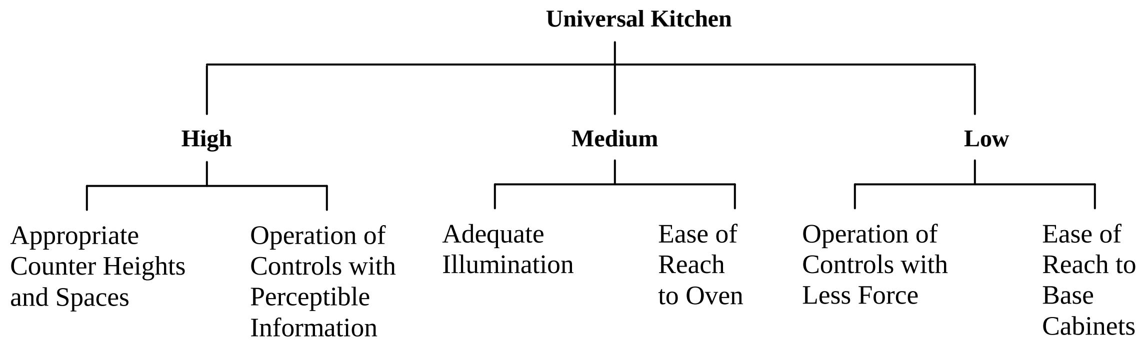


Figure 5.3. The resulting PG categories of a universal kitchen

The resulting PG distribution of the six UKRs with respect to each specialist was illustrated in Table 5.8. During the PG process, each specialist evaluated the UKRs according her/his discipline specific expertise. Industrial designers highlighted the necessity of user-friendly features on product-related issues, such as appliance design, the interface design of controls. They stated that the today's kitchen products and their interfaces are not designed to accommodate diverse user needs and are unsuitable for disabled and elderly resulted from the lack of ergonomic data. On the other hand, both interior architects and architects focused more on the space–related issues and stated that appropriate counter designs and adequate illumination levels were the essential design requirements of a universal kitchen, and believed that a kitchen could not function without proper application of them. However, regardless of their discipline, all the specialists commonly emphasized the crucial necessity of pictorial, verbal, tactile and Braille presentation of essential information on controls and distributed the UKR 'Operation of controls with perceptible information' into the high category. According to seven of nine specialists, the availability of multiple methods of interpreting information is the most critical requirement for a universal kitchen to maximize the easy and safe usage by varying abilities.

Table 5.8. The resulting PG distrubitions of the six UKRs.

| **The Six UKRs** | **S1** | **S2** | **S3** | **S4** | **S5** | **S6** | **S7** | **S8** | **S9** | **Mean** |
|---|---|---|---|---|---|---|---|---|---|---|
| Operation of controls with less force | Medium | Medium | Medium | Low | Low | Low | Low | Low | Low | **Low** |
| Appropriate counter heights and spaces | Medium | Medium | Medium | High | High | High | High | High | High | **High** |
| Operation of controls with perceptible information | High | High | High | High | Medium | High | High | High | Medium | **High** |
| Adequate illumination | Medium | Medium | Medium | High | Medium | Medium | High | High | High | **Medium** |
| Ease of reach to oven | High | High | High | Medium | Medium | Medium | Medium | Medium | Medium | **Medium** |
| Ease of reach to base cabinets | Low | Low | Low | Medium | Low | Low | Low | Medium | Medium | **Low** |

S1, S2, S3- Product designer
S4, S5, S6- Interior architects
S7, S8, S9- Architects

### 5.2.3 Application of the Analytic Hierarchy Process (AHP) Technique to Derive the Priority Weights

There were no time lapses between the PG and the AHP technique application. Having completed the PG, each specialist continued the prioritization process with the AHP technique using the cost-value approach. First, they performed the pair-wise comparisons of the six UKRs under the high, medium and low categories and later, the pair-wise comparisons of all the sub-UKRs by using a 1-5 scale (See Appendix F for the pair-wise comparison sheets of the six UKRs and all the sub-UKRs for value). The calculations of priority weights of both the UKRs and sub-UKRs were performed with the computing tool MATLAB.

#### 5.2.3.1 The Priority Weights of the Six UKRs

This prioritization included a total of 3 pair-wise comparisons for value and cost, respectively; 2x1/2=1 comparison for high category; 2x1/2=1 comparison for medium category and 2x1/2=1 comparison for low category. Since each PG category was composed of the two UKRs, the pair-wise comparison judgments both for value and cost were entered in 2x2 matrices (See Appendix G for the comparison matrices of the six UKRs for value and cost). The judgments were the mean values of the used 1-5 scale with respect to the nine specialists. The resulting value and cost priority weights of high, medium and low categories were illustrated in Figure 5.4, 5.5 and

5.6. As it can be analyzed from the figures, both the determined value and estimated cost of each UKR is relative and based on a ratio scale. In each figure, the first UKR is about 3 times as valuable and/or expensive as the second UKR.

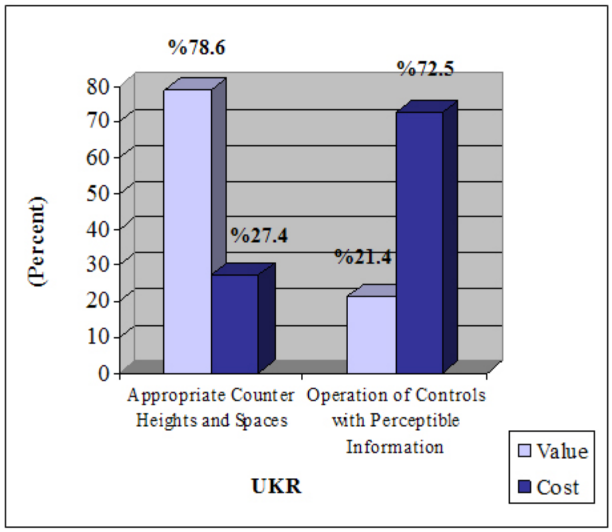


Figure 5.4. Priority weights of the two UKRs in the high category.

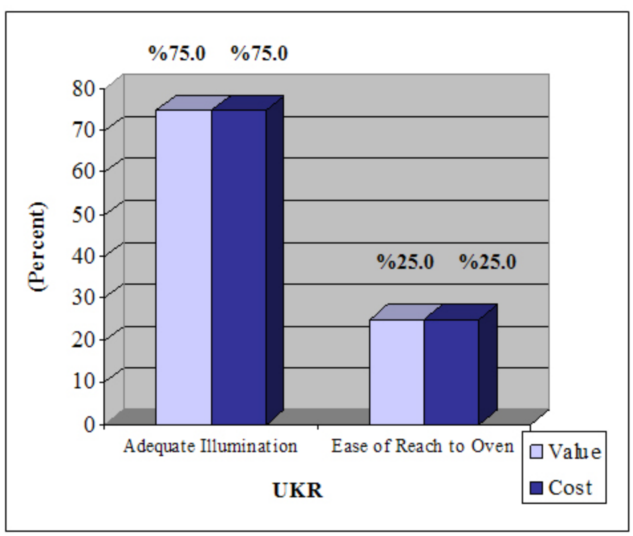


Figure 5.5. Priority weights of the two UKRs in the medium category.

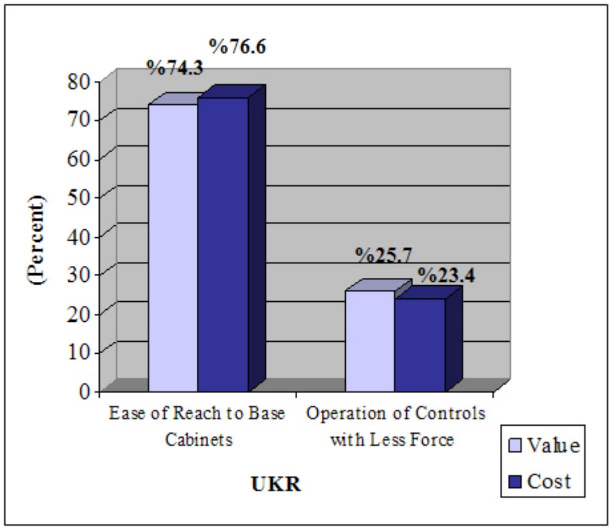


Figure 5.6. Priority weights of the two UKRs in the low category.

#### 5.2.3.2 The Priority Weights of All the Sub-UKRs

The same prioritization process was repeated for all the sub-UKRs. Each specialist made 116 pair-wise comparisons for value and cost respectively. Table 5.9 listed the required number of pair-wise comparisons for the sub-UKRs under each category. As in the prioritization process of the six UKRs, the pair-wise comparison mean values from the used 1-5 scale were set up in the row and columns of the matrices (See Appendix H for the comparison matrices of all the sub-UKRs for value and cost).

Table 5.9. The number of pair-wise comparisons for all the sub-UKRs.

| Categories | Name of the UKRs | Number of the sub-UKRs | Number of Pair-wise Comparisons | Total |
|---|---|---|---|---|
| **High** | Appropriate counter heights and spaces | 7 | 7x6/2=21 | |
| | Operation of controls with perceptible information | 8 | 8x7/2=28 | **49** |
| **Medium** | Adequate Illumination | 4 | 4x3/2=6 | |
| | Ease of Reach to Oven | 3 | 3x2/2=3 | **9** |
| **Low** | Operation of controls with less force | 11 | 11x10/2=55 | |
| | Ease of reach to base cabinets | 3 | 3x2/2=3 | **58** |

The resulting priority weights of the sub-UKRs are illustrated in Figure 5.7, 5.8, 5.9, 5.10, 5.11 and 5.12 in the order of their belonging PG categories. According to Figure 5.7, the most valuable sub-UKR under the ‘Appropriate counter heights and spaces’ is the requirement Q22, which is an appropriate counter space on each side of the cooking surface. All the universal design specialists commonly stated that the risk of burns and accidents caused by transferring hot pans and plates plays the most important role in designing a safe kitchen environment. They highlighted that the provision of a consistent level of adjoining work surfaces for preparing, sliding and transferring hot and boiling foods should have a higher value rank than the other counter-related design requirements. Therefore, the sub-UKR number Q22 accounted for 30.5 percent of the total value. The most expensive sub-UKR is the requirement Q18, which is the use of the whole counter surface without uncomfortable postures. It constitutes 27.5 percent of the total cost. The least expensive sub-UKR number Q17, an appropriate counter height, is about 4 times as cheap to implement as the requirement Q18.

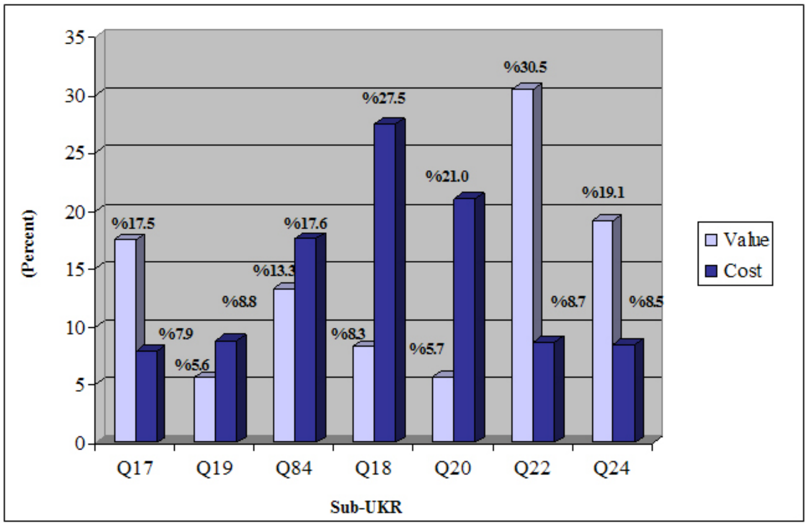


Figure 5.7. Priority weights of the sub-UKRs under 'Appropriate counter heights and spaces'.

Figure 5.8 indicates the priority weights of the eight sub-UKRs under the 'Operation of controls with perceptible information'. The most valuable requirement is the sub-UKR number Q31, which is the availability of warning features of the cook-top about potential hazards. According to the nine specialists, compared to the other appliances, cook-top controls are the most critical controls for a universal kitchen when selecting the most appropriate cook-top model. They should have warning lights, braille features and audible clicks to indicate that the cook-top is turned on or off. So, its value percentage is 32.2 of the total value and is about 10 times as valuable as the requirement Q56- the provision of helpful feedbacks by the refrigerator controls as the person use it. The most expensive requirement is the requirement 61, which is the provision of helpful feedbacks by the cook-top controls as the person use it. It accounted for 23.5 percent of the total cost, whereas the least expensive requirement Q25, which is the rounded edges on the counter, constituted only 2.3 of the total cost.

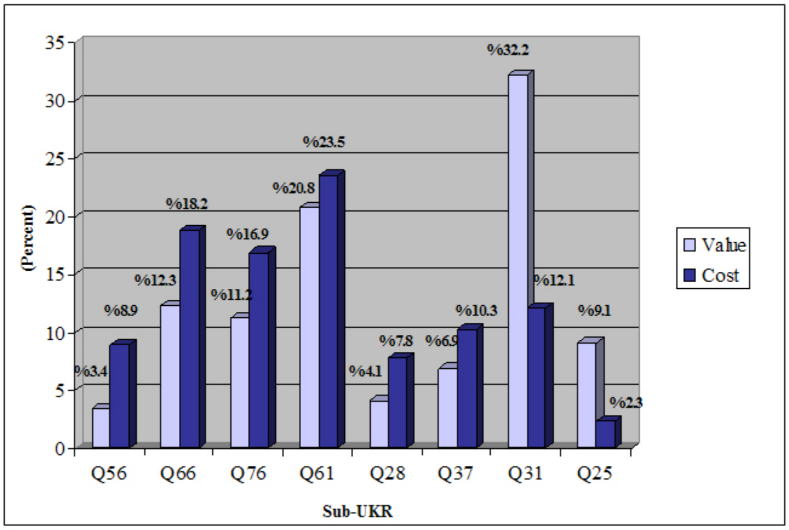


Figure 5.8. Priority weights of the sub-UKRs under 'Operation of controls with perceptible information'.

According to Figure 5.9, the most valuable sub-UKR under the 'Adequate illumination' is the requirement Q82, which is the adequate illumination level above the cook-top. Similar to the previous two value distributions, once again the sub-UKR related with cook-top accounted for the highest percentage of the total value, 49.3 percent. The specialists emphasized that effective task lighting above the cook-top is a vital design requirement of a universal kitchen that maximizes the ease and comfort of cooking and minimizes hazards of accidental burns. The most expensive sub-UKR is the requirement Q81, which is the adequate illumination level over the working surfaces. It constitutes 51.5 percent of the total cost. It is about 8 times as expensive to implement as the requirement Q79, which is adequate natural light in the kitchen.

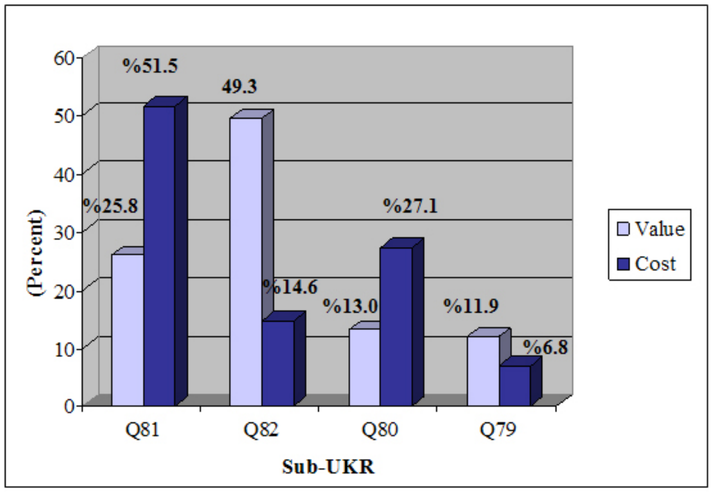


Figure 5.9. Priority weights of the sub-UKRs under 'Adequate illumination'.

Figure 5.10 indicates the priority weights of the three sub-UKRs under the 'Ease of reach to oven'. The most valuable requirement is the requirement Q23, which is an appropriate counter space at least on one side of the oven at the same level as the rack. Its value percentage is 40.9 of the total value because of the same reasons discussed in the sub-UKR number Q22. The most expensive requirement is the requirement 33, which is the ease of reach to all the essential elements of the oven from the positions where the person would like to be in. It accounted for 55.1 percent of the total cost, whereas the least expensive requirement Q23, which is an appropriate counter space at least on one side of the oven at the same level as the rack, constituted only 13.2 of the total cost.

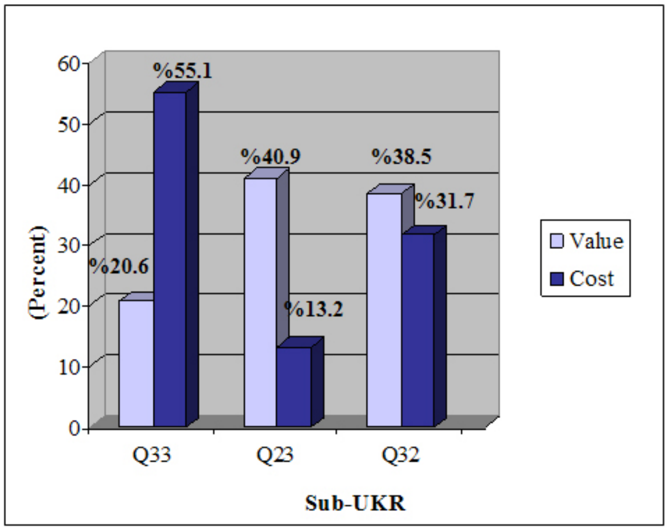


Figure 5.10. Priority weights of the sub-UKRs under ‘Ease of reach to oven’.

According to Figure 5.11, both the most valuable and most expensive sub-UKR under the ‘Operation of controls with less force’ is the requirement Q47, which is the operation of the receptacles with less force. It accounted for 23.7 percent of the total value and for 19.9 of the total cost. Interestingly, both the least valuable and least expensive requirement is the same sub-UKR number Q55, which is the simplicity in operating the refrigerator controls. The requirement Q47 is about 5 times as valuable and expensive to implement as the requirement Q55.

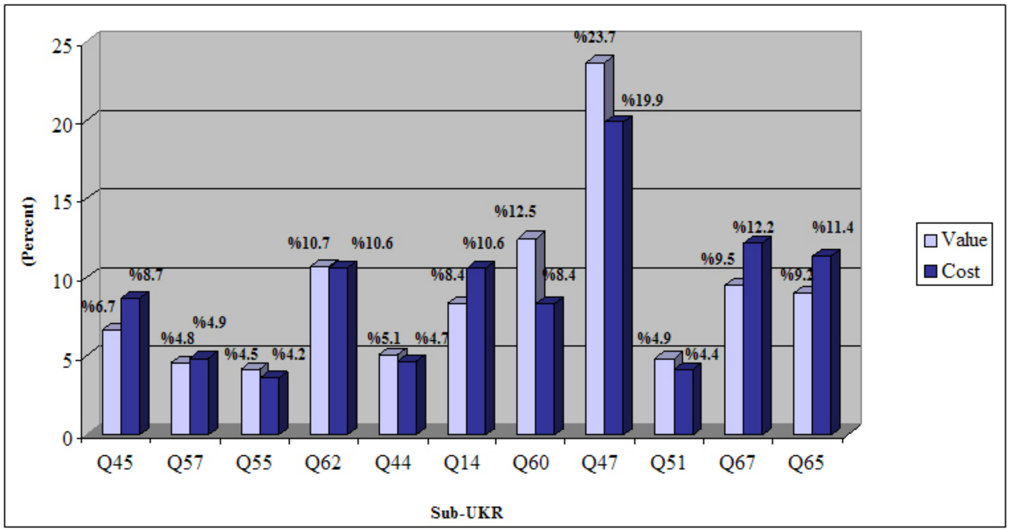


Figure 5.11. Priority weights of the sub-UKRs under 'Operation of controls with less force'.

Finally, Figure 5.12 indicates the priority weights of the last three sub-UKRs under the 'Ease of reach to base cabinets'. Both the most valuable and expensive requirement is the requirement Q12, which is the effective end efficient use of corner cabinets by 360° rotating mechanisms/lazy-susan units/moon swing-out shelves. It constitutes 58.4 percent of the value and of 46.8 of the total cost. According to the universal design specialists, the corner storage usage is problematic in the most of the kitchens due to the implementation costs of the rotating shelves. The lack of appropriate mechanisms inside of the dead corner cabinets leads accessibility and visibility problems. The least expensive requirement is the sub-UKR number Q7, which is the ease of reach to the low portions of the base cabinets. It accounted for 11.5 percent of the total cost.

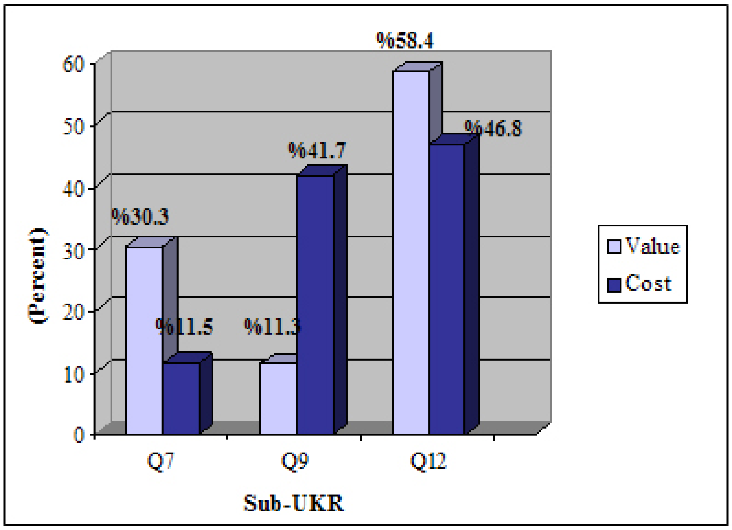


Figure 5.12. Priority weights of the sub-UKRs under 'Ease of reach to base cabinets'.

### 5.2.4 Calculation of Each Requirement's Relative Cost-Value Priority

In this step of the second stage, the derived the priority weights of the UKRs and sub-UKRs are plotted along the x-y axis of the cost-value graphs to visualize the three priority ratio categories of all the requirements. The priority categories illustrate which of the UKRs and sub-UKRs have high, medium and low contributions to the universal kitchen environment with respect to their cost-value ratio. First, the UKRs were depicted into the cost-value graphs and later, all the sub-UKRs to analyze the ideal ratio of design requirements, which are the most valuable but the least expensive.

#### 5.2.4.1 Cost-Value Analysis of the Six UKRs

The cost-value graph of the UKRs was indicated in Figure 5.13. The UKRs under the same PG category were represented with the same color and symbol. The three areas in the graph that are divided with lines represent the different scales of contribution of the requirements. Three of the six UKRs are located in the high ratio of value to cost contribution area of the graph. Their value to cost ratio was higher than 2. According to Figure 5.13, regarding two UKRs in the high PG category the 'Appropriate counter heights and spaces' has a higher value to cost ratio compared to the 'Operation of controls with perceptible information'.  Thus, counter-related design requirements should be implemented first. The two UKRs under the medium PG category are in the high ratio of value to cost contribution area of the graph and have same value to cost ratio compared to each other so that their implementation priority does not matter. The last two requirements under the low PG category are located in the medium ratio of value to cost contribution area and have nearly the same cost-value ratio.

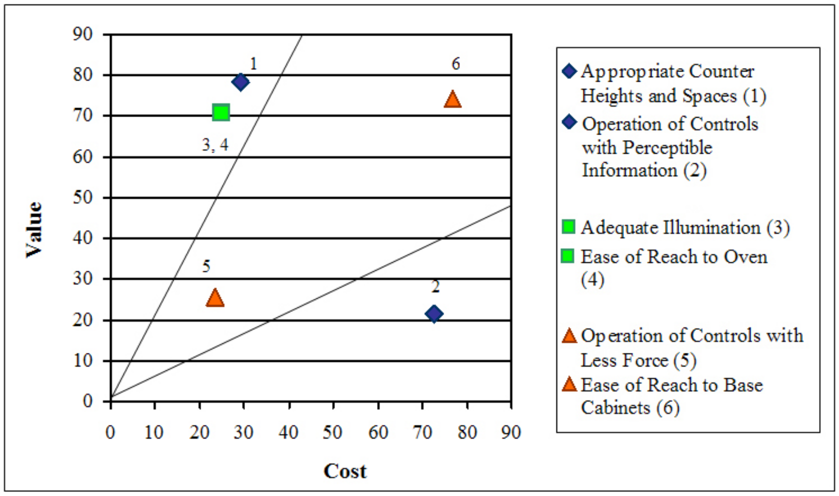


Figure 5.13. Cost-value graph for the UKRs.

#### 5.2.4.2 Cost-Value Analysis of All the Sub-UKRs

The values of all the sub-UKRs were plotted against their estimated costs of implementation in Figure 5.14, 5.15, 5.16, 5.17, 5.18 and 5.19. The contribution of each sub-UKR is different in the six sets of cost-value graphs. Rather than selecting the requirements on an arbitrary basis, these graphs are important in terms of selecting the best set of requirements under each UKR. Figure 5.14 indicates the cost-value graph of the seven sub-UKRs under the ‘Appropriate counter heights and spaces’. The sub-UKRs number Q22, 24 and 17, which are related with the appropriate counter height and adjacent counter areas have high contribution to a universal kitchen design. The sub-UKRs number Q19 and 84, which correspond to counter material and various counter heights, are located in the medium ratio area. Finally, the last requirements number 18 and 20, which are related with the comfortable usage of counter and pull-out work surfaces, are in the low value to cost ratio area because of their high implementation costs.

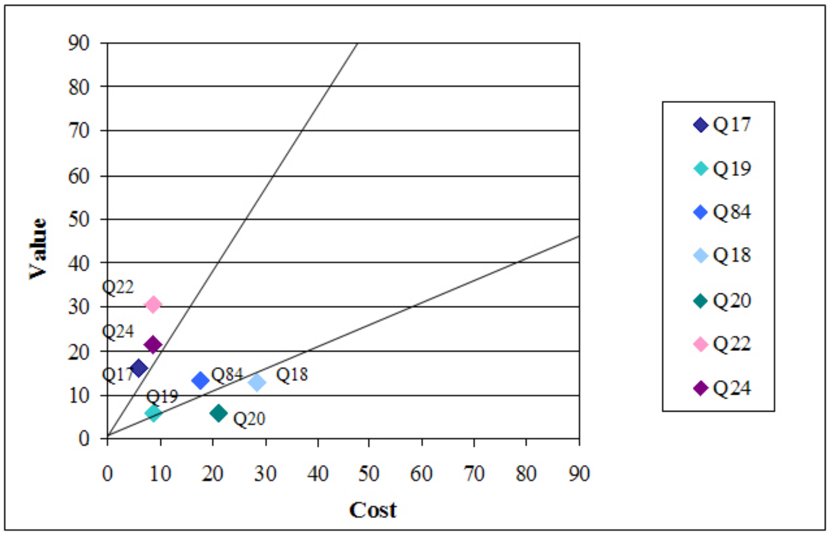


Figure 5.14. Cost-value graph for the sub-UKRs under ‘Appropriate counter heights and spaces’.

The cost-value graph of the eight sub-UKRs under the ‘Operation of controls with perceptible information’ is outlined in Figure 5.15. According to the graph, there are no sub-UKRs with low priority ratio. The two sub-UKRs number 25 and 31, which are rounded edges and availability of warning features of cook-top, bring high contribution to the universal kitchen, whereas the rest of the 6 six sub-UKRs are medium contributors.

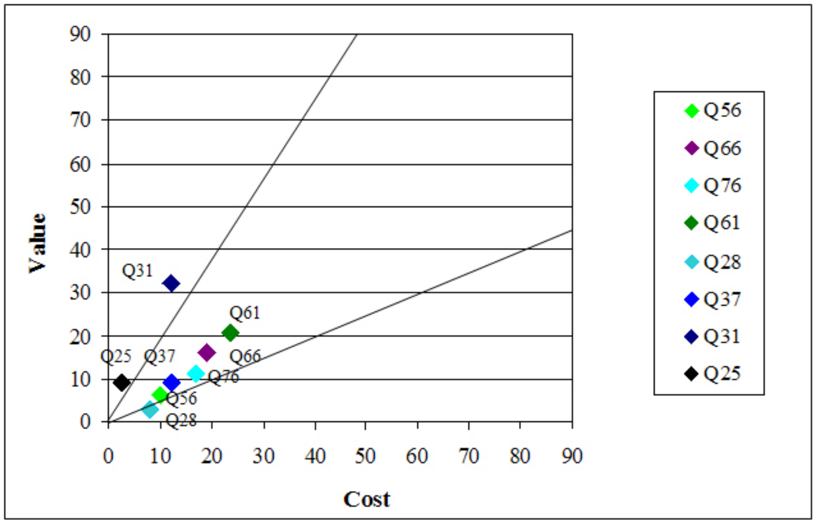


Figure 5.15. Cost-value graph for the sub-UKRs under ‘Operation of controls with perceptible information’.

Figure 5.16 indicates the cost-value graph of the four sub-UKRs under the ‘Adequate illumination’. The sub-UKR number 82, which is the adequate illumination above the cook-top, has the highest value to cost ratio and sub-UKR number 80, which is the adequate artificial light, has medium value to cost ratio. However, the other two requirements Q79 and 81 are in-between the areas of high-medium value to cost ratio and medium-low value to cost ratio, respectively. Their ratio ranking could be changed with respect to the budget estimations. If the implementation costs of these two sub-UKRs were reduced based on the kitchen design area, then they could be depicted as high and medium contributors.

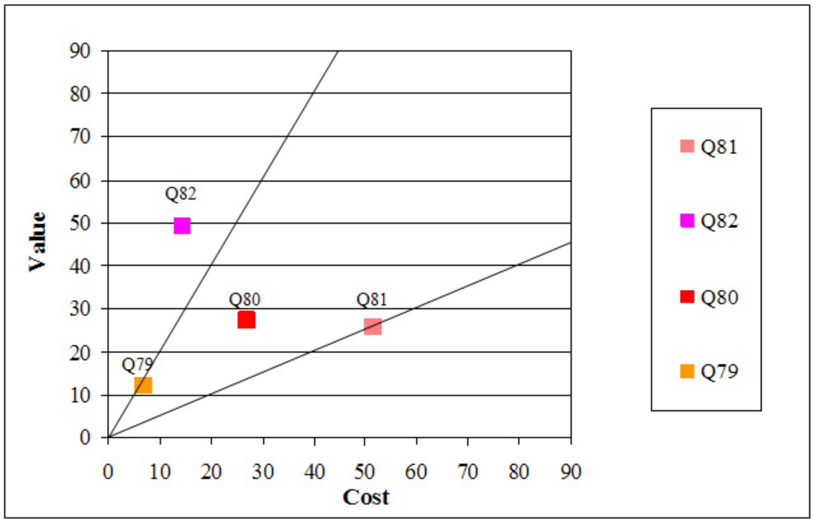


Figure 5.16. Cost-value graph for the sub-UKRs under ‘Adequate illumination’.

According to Figure 5.17, the three sub-UKRs under the ‘Ease of reach to oven’ were equally plotted into the three areas of the cost-value graph. Although the requirement Q32, which is related to close approach to oven, has nearly as same value weight as the requirement Q23, which is the provision of an adjacent counter space on one side of oven, Q32 is located in the medium area of the graph because of its expensive implementation cost. The final sub-UKR number Q33, which is the ease of reach to all essential elements of oven, is depicted as a low contributing requirement.

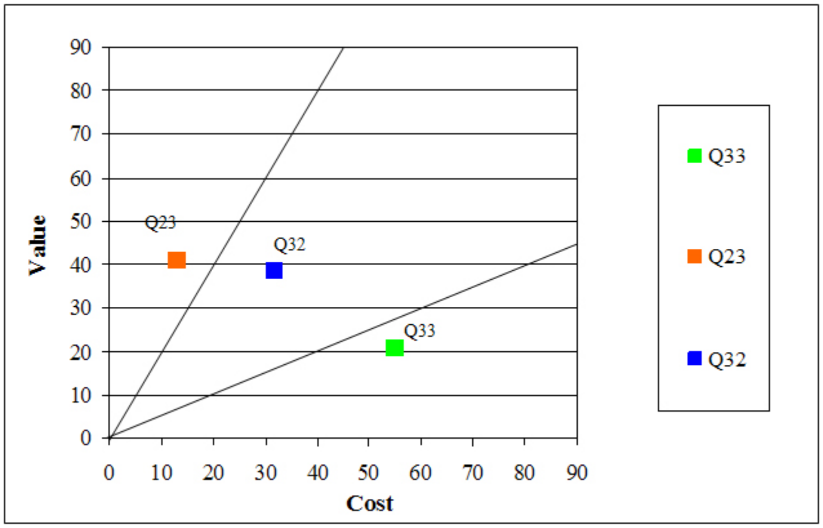


Figure 5.17. Cost-value graph for the sub-UKRs under ‘Ease of reach to oven’.

Figure 5.18 indicates the cost-value graph of the eleven sub-UKRs under ‘Operation of controls with less force’. Since both the value and cost distributions of the requirements are close to each other, it is not possible to observe a skewed distribution from the graph, i.e. there are no extreme cost-value ratios. All the 11 sub-UKRs are located in the medium ratio category. However, sub-UKR number Q47, which is operation of the receptacles with less force, differentiated from the rest of the requirements because of its higher value to cost ratio.

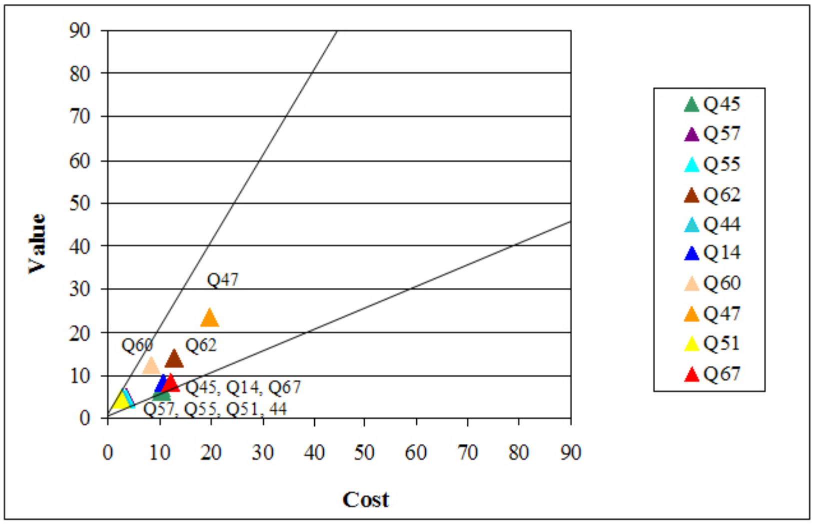


Figure 5.18. Cost-value graph for the sub-UKRs under 'Operation of controls with less force'.

Finally, in Figure 5.19 the three sub-UKRs of the last UKR, 'Ease of reach to base cabinets', are illustrated. Similar to Figure 5.17, the 3 UKRs are equally plotted into the three areas of the cost-value graph. Although the sub-UKR number Q12, which is the effective and efficient usage of corner cabinets, has the highest value weight compared to the requirement Q7, which is the ease of reach to the low portions of base cabinets, Q12 is located in the medium area of the graph because of its expensive implementation cost.

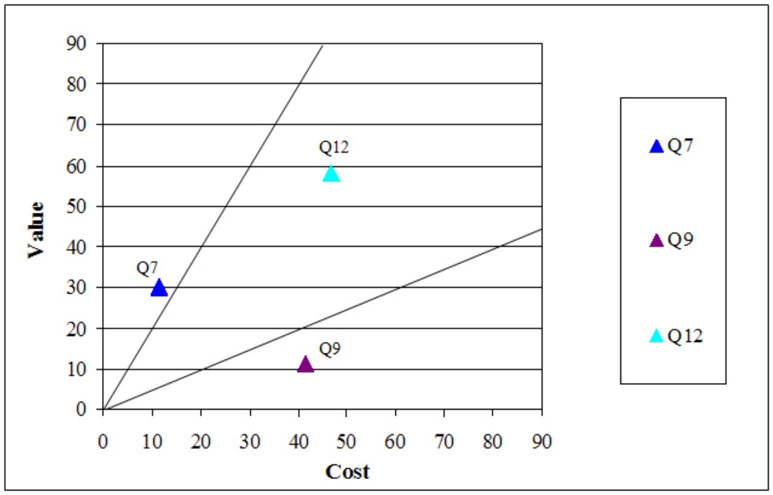


Figure 5.19. Cost-value graph for 'Ease of reach to base cabinets'.

### 5.2.5 Determination of the Relative Overall Importance Degrees of All the UKRs and Sub-UKRs

The relative overall importance degree of one kitchen requirement to another is called its global weight, when all the requirements are considered jointly with respect to the whole universal kitchen. During this final step of the second stage, the global weights of the sub-UKRs are given by multiplying the priority weight of each sub-UKR above by the corresponding UKR. Figure 5.20, 5.21 and 5.22 summarize the global weights of the sub-UKRs under the three PG categories for both value and cost, respectively. The three figures also represent the consistency ratios of each UKR, which are far below the maximum value of 0.1 as suggested by the literature. So, the results from the prioritization process are validated to be consistent, accurate and reliable.

**High PG Category**

| UKR | Sub-UKRs | Value-Cost Priority Ratio | Value, Cost Weights | Global Value, Cost Weights |
|---|---|---|---|---|
| **Appropriate counter heights and spaces**<br><br>High ratio<br>(0.786, 0274)<br><br>CR=0.030 | Q22. An appropriate counter space on each side of the cooking surface | High ratio | 0.305<br>0.087 | 0.305x0.786=0.239<br>0.087x0.274=0.023 |
| | Q24. An appropriate counter space at least on one side of the sink | High ratio | 0.191<br>0.085 | 0.191x0.786=0.150<br>0.085x0.274=0.023 |
| | Q17. An appropriate counter height | High ratio | 0.175<br>0.079 | 0.175x0.786=0.137<br>0.079x0.274=0.021 |
| | Q84. A heat-resistant counter top material | Medium ratio | 0.133<br>0.176 | 0.133x0.786=0.104<br>0.176x0.274=0.048 |
| | Q19. Counters at various heights | Medium ratio | 0.056<br>0.088 | 0.056x0.786=0.044<br>0.088x0.274=0.024 |
| | Q18. Use of the whole surface of the counter without uncomfortable postures | Low ratio | 0.083<br>0.275 | 0.083x0.786=0.065<br>0.275x0.274=0.075 |
| | Q20. Pull-out work surfaces | Low ratio | 0.057<br>0.210 | 0.057x0.786=0.044<br>0.210x0.274=0.057 |

| UKR | Sub-UKRs | Value-Cost Priority Ratio | Value, Cost Weights | Global Value, Cost Weights |
|---|---|---|---|---|
| **Operation of controls with perceptible information**<br><br>Low ratio<br>(0.214, 0.725)<br><br>CR=0.027 | Q31. Availability of warning features of the cook-top about potential hazards | High ratio | 0.322,<br>0.121 | 0.322x0.214=0.068<br>0.121x0.725=0.087 |
| | Q25. Rounded edges on the counter | High ratio | 0.091<br>0.023 | 0.091x0.214=0.019<br>0.023x0.725=0.016 |
| | Q61. Provision of helpful feedbacks by the cook-top controls as the person use it | Medium ratio | 0.208<br>0.235 | 0.208x0.214=0.044<br>0.235x0.725=0.170 |
| | Q66. Provision of helpful feedbacks by the oven controls as the person use it | Medium ratio | 0.123<br>0.182 | 0.123x0.214=0.026<br>0.182x0.725=0.131 |
| | Q76. Provision of helpful feedbacks by the hood controls as the person use it | Medium ratio | 0.112<br>0.169 | 0.112x0.214=0.023<br>0.169x0.725=0.122 |
| | Q37. Availability of warning features of the dishwasher about potential hazards | Medium ratio | 0.069<br>0.103 | 0.069x0.214=0.014<br>0.103x0.725=0.074 |
| | Q56. Provision of helpful feedbacks by the refrigerator controls as the person use it | Medium ratio | 0.034<br>0.089 | 0.034x0.214=0.007<br>0.089x0.725=0.064 |
| | Q28. Availability of warning features of the refrigerator about potential hazards | Medium ratio | 0.041<br>0.078 | 0.041x0.214=0.008<br>0.078x0.725=0.056 |

Figure 5.20. The global weights of the sub-UKRs under the high PG category.

Medium PG Category

| UKR | Sub-UKRs | Value-Cost Priority Ratio | Value, Cost Weights | Global Value, Cost Weights |
|---|---|---|---|---|
| **Adequate illumination**<br><br>High ratio (0.750, 0.750)<br><br>CR=0.019 | Q82. Adequate illumination level above the cook-top | High ratio | 0.493<br>0.146 | 0.493x0.750=0.369<br>0.146x0.750=0.109 |
| | Q79. Adequate natural light in the kitchen | High ratio | 0.119<br>0.068 | 0.119x0.750=0.089<br>0.068x0.750=0.051 |
| | Q80. Adequate artificial light in the kitchen | Medium ratio | 0.130<br>0.271 | 0.130x0.750=0.097<br>0.271x0.750=0.203 |
| | Q81. Adequate illumination level over the working surfaces | Medium ratio | 0.258<br>0.515 | 0.258x0.750=0.193<br>0.515x0.750=0.386 |

| UKR | Sub-UKRs | Value-Cost Priority Ratio | Value, Cost Weights | Global Value, Cost Weights |
|---|---|---|---|---|
| **Ease of reach to oven**<br><br>High ratio (0.250, 0.250)<br><br>CR=0.024 | Q23. An appropriate counter space at least on one side of the oven at the same level as the rack | High ratio | 0.409<br>0.132 | 0.409x0.250=0.102<br>0.132x0.250=0.033 |
| | Q32. Close approach to the oven | Medium ratio | 0.385<br>0.317 | 0.385x0.250=0.096<br>0.317x0.250=0.079 |
| | Q33. Ease of reach to all the essential elements of the oven from the positions where the person would like to be in | Low ratio | 0.206<br>0.551 | 0.206x0.250=0.051<br>0.551x0.250=0.137 |

Figure 5.21. The global weights of the sub-UKRs under the medium PG category.

Low PG Category

| UKR | Sub-UKRs | Value-Cost Priority Ratio | Value, Cost Weights | Global Value, Cost Weights |
|---|---|---|---|---|
| **Operation of controls with less force**<br><br>Medium ratio (0.257, 0.234)<br><br>CR=0.010 | Q47. Operation of the receptacles with less force | Medium ratio | 0.237<br>0.199 | 0.237x0.257=0.060<br>0.199x0.234=0.046 |
| | Q67. Operation of the oven controls with less force | Medium ratio | 0.095<br>0.122 | 0.095x0.257=0.024<br>0.122x0.234=0.028 |
| | Q65. Simplicity in operating the oven controls | Medium ratio | 0.092<br>0.114 | 0.092x0.257=0.023<br>0.114x0.234=0.026 |
| | Q14. Use of the cabinet door handles with less force | Medium ratio | 0.084<br>0.106 | 0.084x0.257=0.021<br>0.106x0.234=0.024 |
| | Q60. Simplicity in operating the cook-top controls | Medium ratio | 0.125<br>0.084 | 0.125x0.257=0.032<br>0.084x0.234=0.019 |
| | Q45. Operation of the faucet with less force | Medium ratio | 0.067<br>0.087 | 0.067x0.257=0.017<br>0.087x0.234=0.020 |
| | Q57. Operation of the refrigerator controls with less force | Medium ratio | 0.048<br>0.049 | 0.048x0.257=0.012<br>0.049x0.234=0.011 |
| | Q55. Simplicity in operating the refrigerator controls | Medium ratio | 0.045<br>0.042 | 0.045x0.257=0.011<br>0.042x0.234=0.009 |
| | Q62. Operation of the cook-top controls with less force | Medium ratio | 0.107<br>0.106 | 0.107x0.257=0.027<br>0.106x0.234=0.024 |
| | Q44. Simplicity in operating the faucet | Medium ratio | 0.051<br>0.047 | 0.051x0.257=0.013<br>0.047x0.234=0.010 |
| | Q51. Operation of the switches with less force | Medium ratio | 0.049<br>0.044 | 0.049x0.257=0.012<br>0.044x0.234=0.010 |

| UKR | Sub-UKRs | Value-Cost Priority Ratio | Value, Cost Weights | Global Value, Cost Weights |
|---|---|---|---|---|
| **Ease of Reach to Base Cabinets**<br><br>Medium ratio (0.743, 0.766)<br><br>CR=0.007 | Q7. Ease of reach to the low portions of the base cabinets | High ratio | 0.303<br>0.115 | 0.303x0.743=0.225<br>0.115x0.766=0.088 |
| | Q12. Effective end efficient use of corner cabinets by 360° rotating mechanisms/lazy-susan units/moon swing-out shelves | Medium ratio | 0.584<br>0.468 | 0.584x0.743=0.433<br>0.468x0.766=0.358 |
| | Q9. Ease of use of the rear portions of the base cabinets | Low ratio | 0.113<br>0. 417 | 0.113x0.743=0.083<br>0.417x0.766=0.319 |

Figure 5.22. The global weights of the sub-UKRs under the low PG category.

## 5.3 Stage III: Incorporation of the Derived Priorities into the CAUD Plug-in Tool

In the final stage of the development of the CAUD plug-in tool, the study deals with incorporating the derived priority weights in the previously defined capabilities of the CAUD plug-in tool. The primary goal of interfacing the prioritized UKRs is to provide an integrated CAUD medium, where designers can be informed about the cost-value ratios of each UKR and sub-UKR in the analysis, synthesis and evaluation operations while producing and evaluating universal kitchen design solutions. In this respect, during this stage first a priority manager interface is designed, in which designers can identify the necessary priority information from the SketchUp drawing area. Secondly, a three-dimensional (3D) universal kitchen design solutions constructed by using the plug-in tool. Finally, the universal kitchen design solution is evaluated by developing the 'Priority Check' interface and 'Universal Design Checklist' interface.

### 5.3.1 Interaction of the Priority Manager with the Defined Capabilities of the Plug-in Tool

The 'Priority Manager' interface can be a useful computation tool in successfully inputting the right and relevant set of requirement priorities to the operations of the design process. Figure 5.23 illustrates the interaction of the 'Priority Manager' interface with the defined capabilities of the CAUD plug-in tool. It allows designers to utilize the universal design to-do list, dimensional standards, design guidelines, use-cases, feedbacks from critics, priority check and universal design checklist based on objective assessments and levels of priority rather than subjective and experience-based. It acts like a filter database before analyzing, generating and assessing universal kitchen solutions.

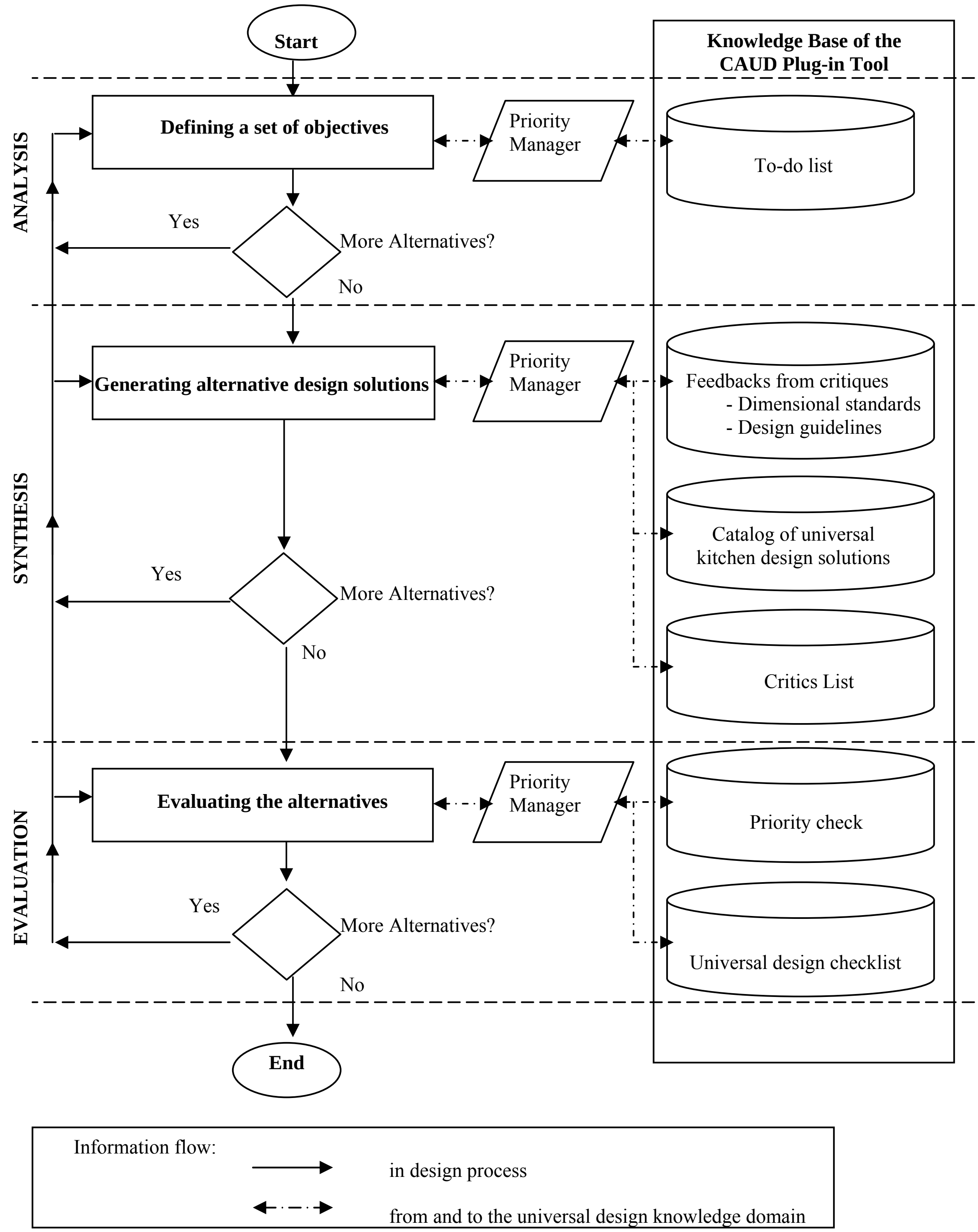


Figure 5.23. Flowchart of the universal design support scheme of the CAUD plug-in tool combined with the 'Priority Manager' interface.

The designer can activate the interface by selecting it from the Plug-ins menu of the SketchUp software program. Based on the derived priority weights, the interface inputs the importance degrees of both six UKRs and all the sub-UKRs (See Section 5.2.4). The interface consists of navigation views of the UKRs and main information area on the related sub-UKR priorities with add/delete/edit options (Figure 5.24). The information area with the cost-value graph is re-loaded each time when a user chooses a different UKR from the navigation view. The information area also provides designers the ability to edit/delete the existing sub-UKRs and/or add new sub-UKRs including their priority weights. Since requirements are not static and change as the design proceeds, this adding/deleting/editing ability of the 'Priority Manager' interface becomes essential. Moreover, the interface can remain active, while user works on the SketchUp drawing area (Figure 5.25). Through this capability of the interface, designers have the opportunity to access the priority information during different design operations and from each relevant decision point. In this respect, the priority manager interface is an input aid in representing, storing and retrieving the relevant priority information on kitchen requirements. Moreover, such a priority manager interface allows a designer in exploring the kitchen design solution from various perspectives (value and cost), analyze tradeoffs (what-if scenarios regarding the requirement priorities) and in comparing it with other candidate solutions.

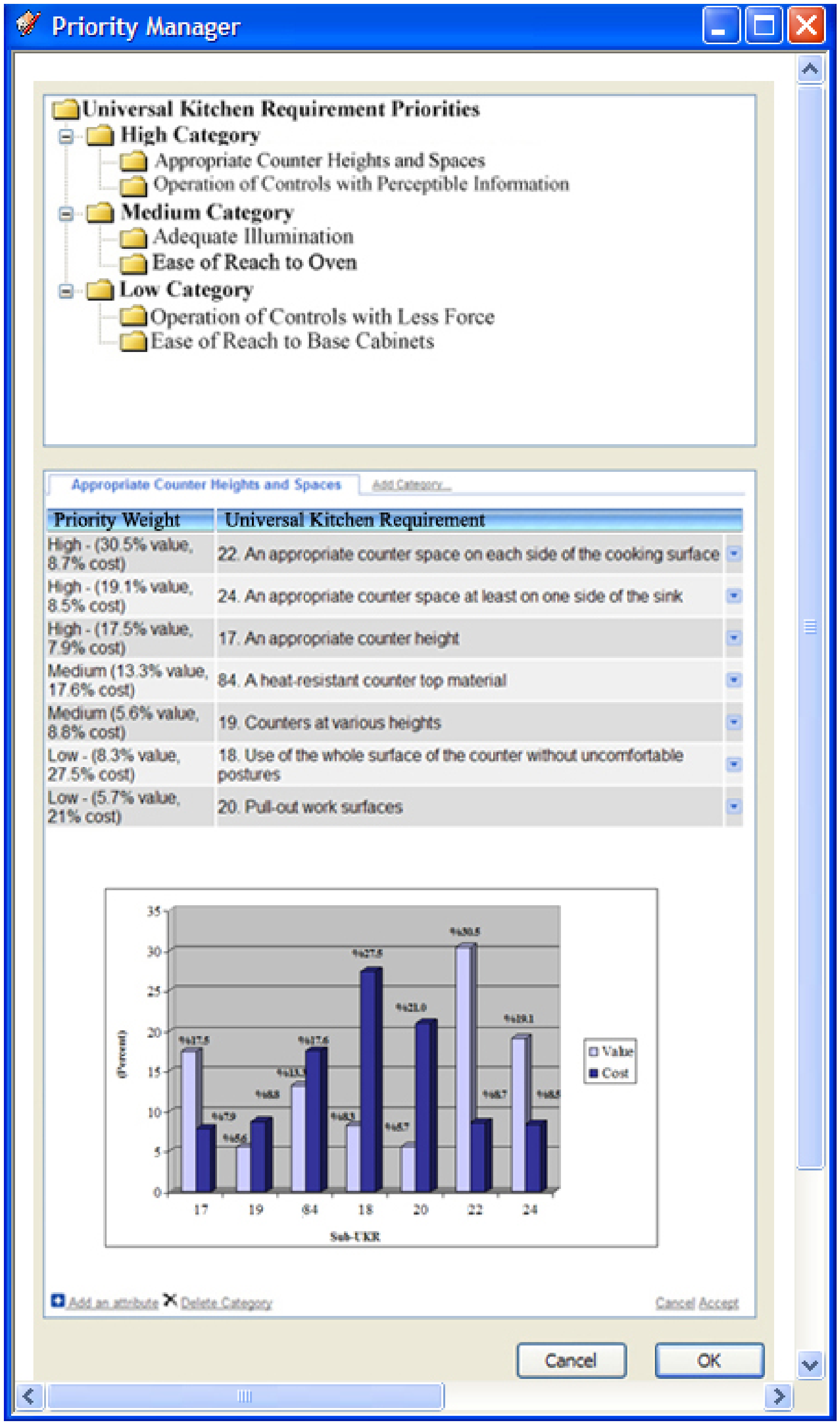


Figure 5.24. The ‘Priority Manager’ interface.

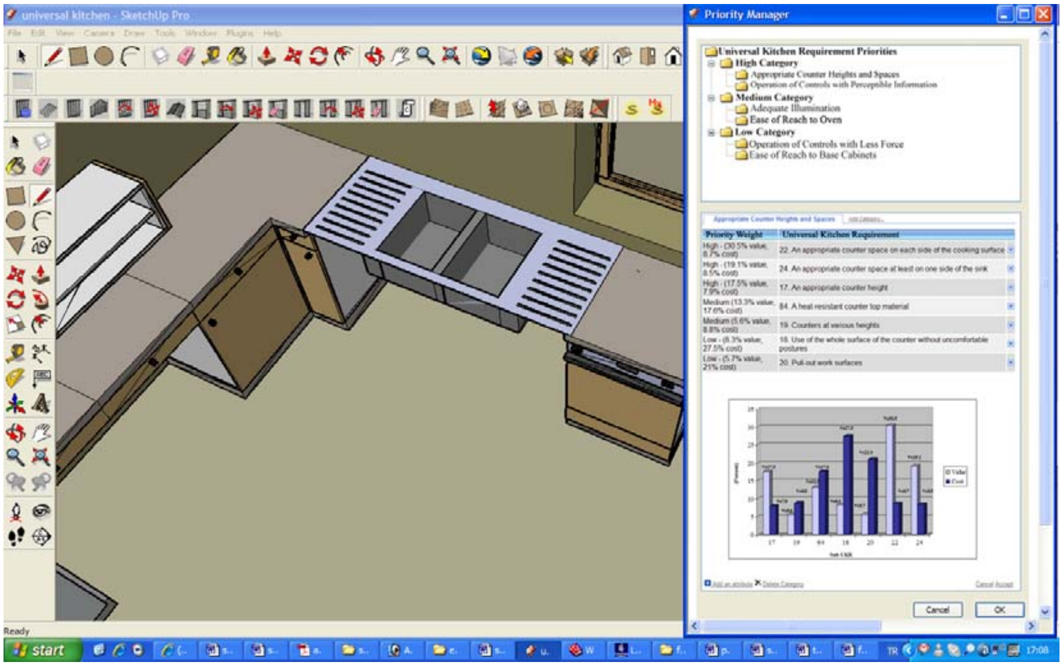


Figure 5.25. A screenshot of the active 'Priority Manager' interface.

### 5.3.2 Construction of a Three-dimensional (3D) Universal Kitchen Design Solution

In this step of the third stage, a universal kitchen design solution is constructed. The universal kitchen design starts with the analysis of correct identification of kitchen requirements; proceeds through the sequence of synthesis activities to seek an ideal kitchen solution and ends with the evaluation of the solution with respect to the requirements. First, within the given dimensions of the real physical space, the boundaries of the interior space are defined. For this purpose, the structural features (walls, doors and windows), electrical receptacles and plumbing connections of the space are drawn through the graphic operators of SketchUp software (Figure 5.26).

This is the basic configuration, from which the project develops. The ‘To-Do List’ interface is used to list, specify and manipulate the requirement changes. Through the ‘Priority Manager’ interface, the importance degrees of each UKR/sub-UKRs can be resolved and decisions on requirements, which of them discard and/or focus on in more detail, could be determined.

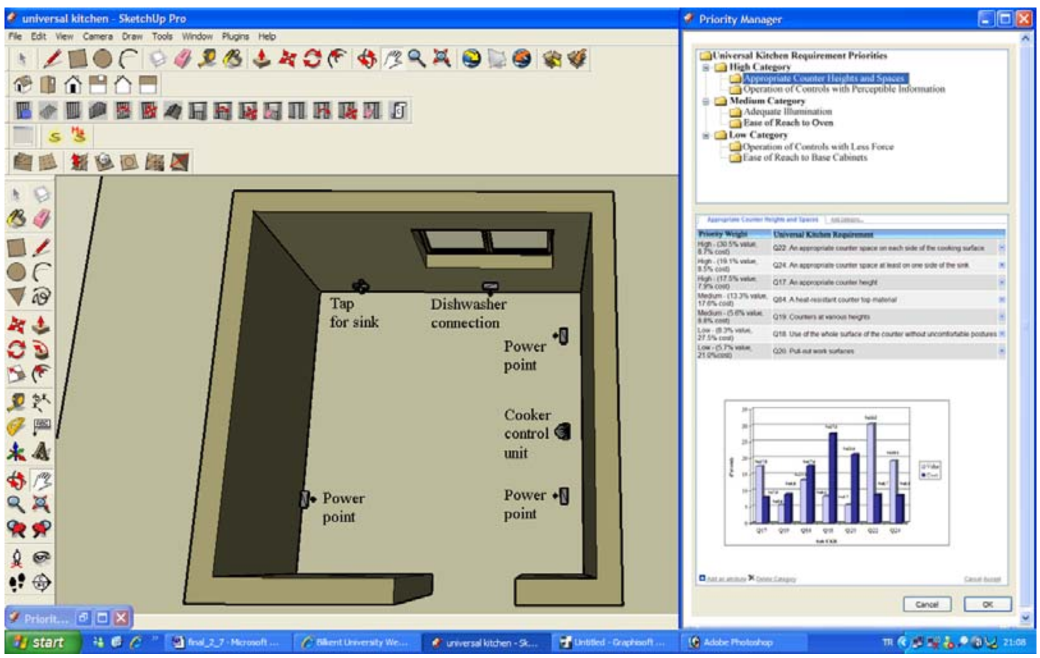


Figure 5.26. The boundaries of the existing room, showing structural features.

The major activity areas and the arrangement of the floor plan are sketched regarding the ‘Dimensional Standards’, ‘Design Guidelines’ and ‘Priority Manager’ interface (Figure 5.27). The active interaction with the ‘Priority Manager’ interface provides support for a priority-based view of the required design manipulations in universal kitchen computing while using the knowledge base of the CAUD plug-in tool. Once the activity centers are planned, then the traffic patterns should be considered. An unobstructed traffic flow is a vital factor that affects the ease of use within the kitchen. Thus, necessary clear floor areas are calculated with respect to the design guidelines and dimensional standards of maneuvering diameter parameters and clear floor space parameters. The work triangle - the sink, cook top and refrigerator- are decided regarding the dimensional standards of clearance at appliances and reach heights parameters. Possible countertops and work surfaces that have to be adjacent to the appliances are considered and proper illumination levels are decided by using the ‘Priority Manager’ interface. Since the study does not deal with design of the appliances, the priority requirements and design guidelines that are related with the appliances are necessary for guiding the designers in choosing a universally designed appliance rather than standard-size/design appliances. The ‘Catalog of Universal Kitchen Design Solutions’ interface is also helpful in providing the necessary kitchen design information that is relevant to the decision process (Figure 5.28).

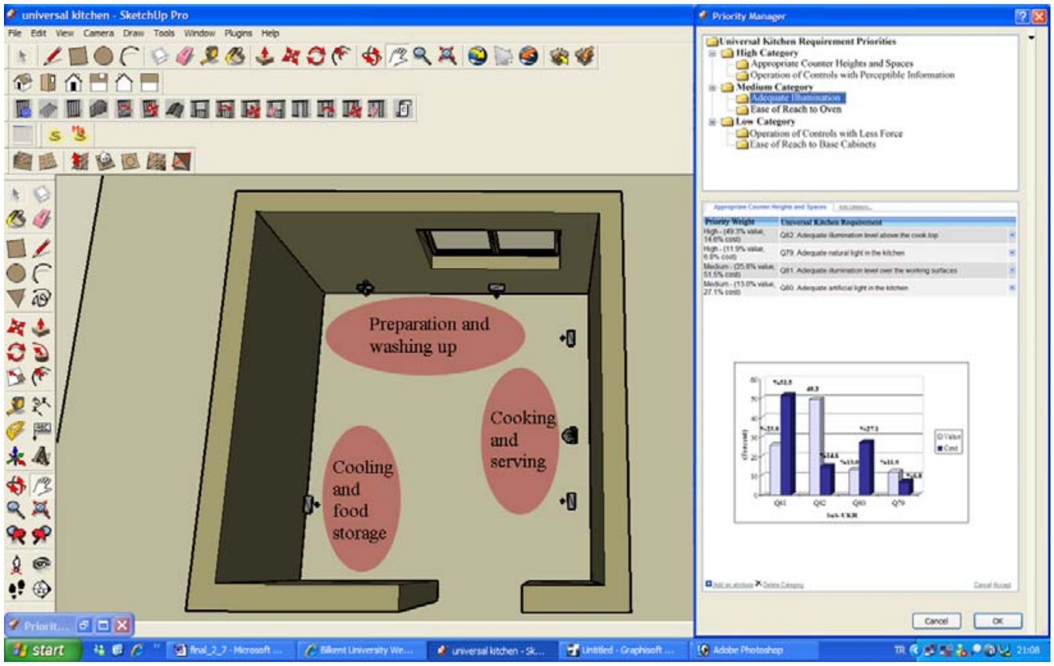


Figure 5.27. The major activity areas regarding the 'Adequate illumination'.

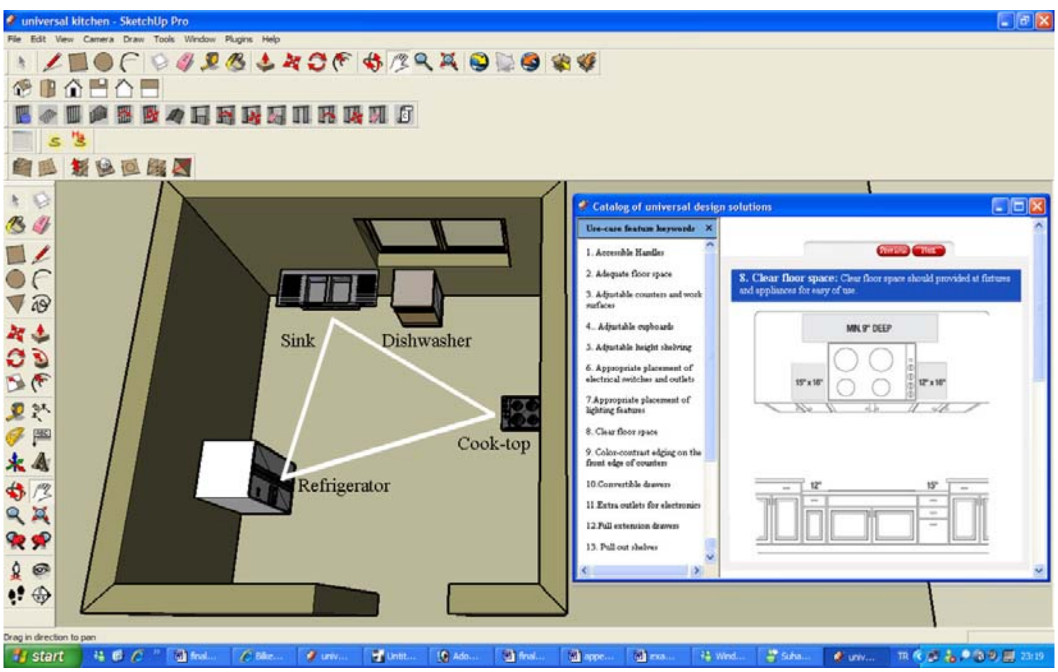


Figure 5.28. Creating the work triangle and placing the appliances.

Finally, the cabinets and storage units are incorporated (Figure 5.29). For increasing the efficiency, the storage needs should be estimated at the beginning of the project by using the ‘To-Do list’ interface. Appropriate shape, size and dimensions of base cabinets, wall cabinets and shelves are provided with respect to the dimensional standards of side and forward approach parameters, reach height parameters, knee space parameters and design guidelines of materials. Depending on the configuration scheme, pull-out shelves, 360 degree rotating mechanisms and other accessible units can be drawn that provide practical links between appliances and counters. The ‘Priority Manager’ interface provides help in meeting the cabinet and storage requirements.

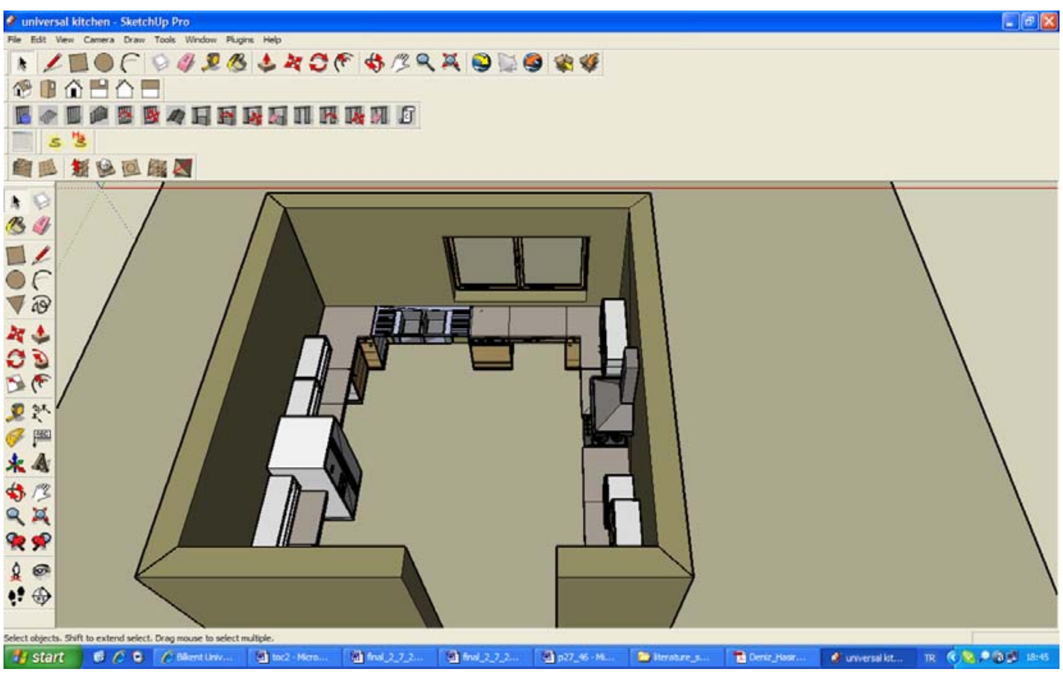


Figure 5.29. Incorporating appropriate shape, size and dimensions of the cabinets.

### 5.3.3 Evaluation of the Universal Kitchen Design Solution

While constructing a three-dimensional (3D) universal kitchen solution, the solution is evaluated whether it satisfies the kitchen requirements and universal design principles. The evaluation process can be done in two stages; (a) during the design process and (b) after the completion of the design process. In the first stage, the 'Priority Check' interface is used to check the solution against each of the six UKR priorities. In this evaluation stage, design and evaluation occur in parallel to support the further development of the project for the most satisfactory solution that meets better universal design priorities. Its advantage is the ease of identifying problems early in the design cycle. In the second stage, the 'Universal Design Checklist' interface is used (See Section 3.5). This stage requires a completed kitchen solution to evaluate how well it satisfies the seven principles of universal design.

#### 5.3.3.1 The 'Priority Check' Interface

The 'Priority Check' interface supports designers on-demand check, where the designer selects a kitchen feature first, which s/he want to evaluate, and then right-clicks on the selected design feature for priority check (Figure 5.30). The data on the 'Priority Check' interface comes from the priority manager and is illustrated under the six sub-menu items each of which corresponds to one of the six UKRs. This interface allows the evaluation of design solutions while designers are engaged in design process, not after. According to the cognitive theory of reflection-in-action, designers can evaluate their designs best during design process rather than after the process (Schon, 1983). Moreover, it also provides means through which the consequences of design decisions are shown and design errors are detected.

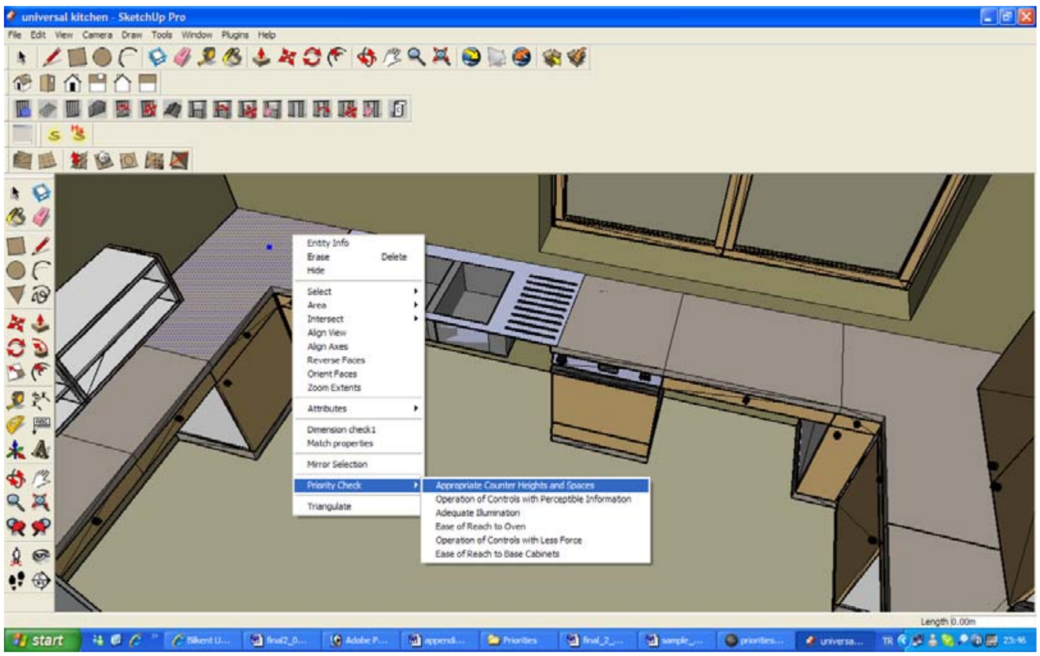


Figure 5.30. The 'Priority Check' with the six sub-menu items.

Beginning from the high category of the UKRs, the process of evaluation is first applied to the designed counter space by selecting and right-clicking on it in the SkectchUp drawing area. Each of the six 'Priority Check' interface is a text-based dialog box that consists of the following two parts; information area and checkbox area (Figure 5.31). The information area displays the priority category of the selected requirement feature and its correlated requirement priorities in order to support designers for a relationship-based view of evaluations and to track improvements of the correlated requirements simultaneously. The checkbox area allows designers to go through each sub-UKR and to check whether it is satisfied or not. Moreover, if there is a dimension related requirement among the sub-UKRs, by checking this requirement the interface automatically pops up a dialog box, which asks the designer to specify two points that she/he wants to check (Figure 5.32). By clicking 'OK' button, s/he is prompted to move the cursor in the direction to be measured so that any two points of the counter are selected and dynamically evaluated against whatever universal design dimensional standard has been defined for this feature (Figure 5.33). As illustrated in Figure 5.31, 5.32 and 5.33 the designed counters are evaluated by using the 'Appropriate counter heights and spaces' interface to identify potential areas for improvement. The priority category of designing appropriate counter heights and spaces is high and its correlated requirements are 'Adequate İllumination', 'Ease of reach to oven' and 'Ease of reach to base cabinets'. In this respect, having evaluated the counters, the three correlated requirements should be also examined because any modification in the counters has effect on these requirements. Coming to sub-UKRs' evaluation, by checking the 'An appropriate counter height' requirement, the interface identifies that the counter height is 90cm, whereas it should be between 73-86cm (Figure 5.33). Thus, the counter height is decreased to meet the required dimensions. The evaluation process is carried out until all the six UKRs are checked, their corresponding design features are modified and their correlated requirements are analyzed. These successive evaluation steps feed back into designers' universal problem solving process and lead them to focus on further development and modifications of unusable and problematic kitchen design features that can remain unnoticed. Each of the six 'Priority Check' interface also guides designers to decide what to rework next.

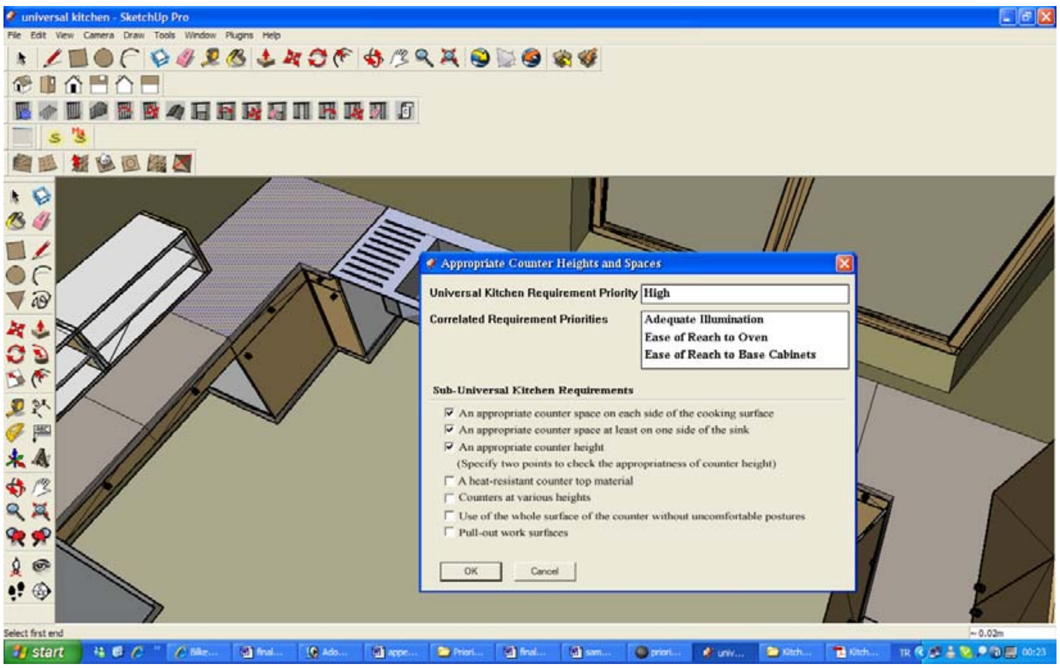


Figure 5.31. The 'Priority Check' interface of the 'Appropriate counter heights and spaces' .

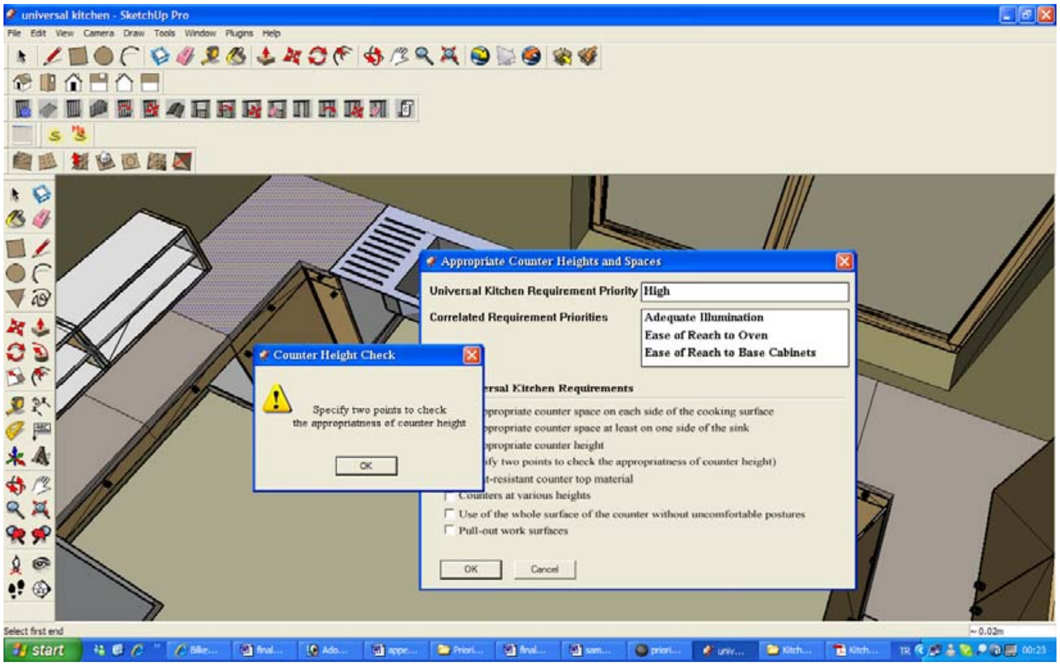


Figure 5.32. The dialog box asking the designer to specify two points to check.

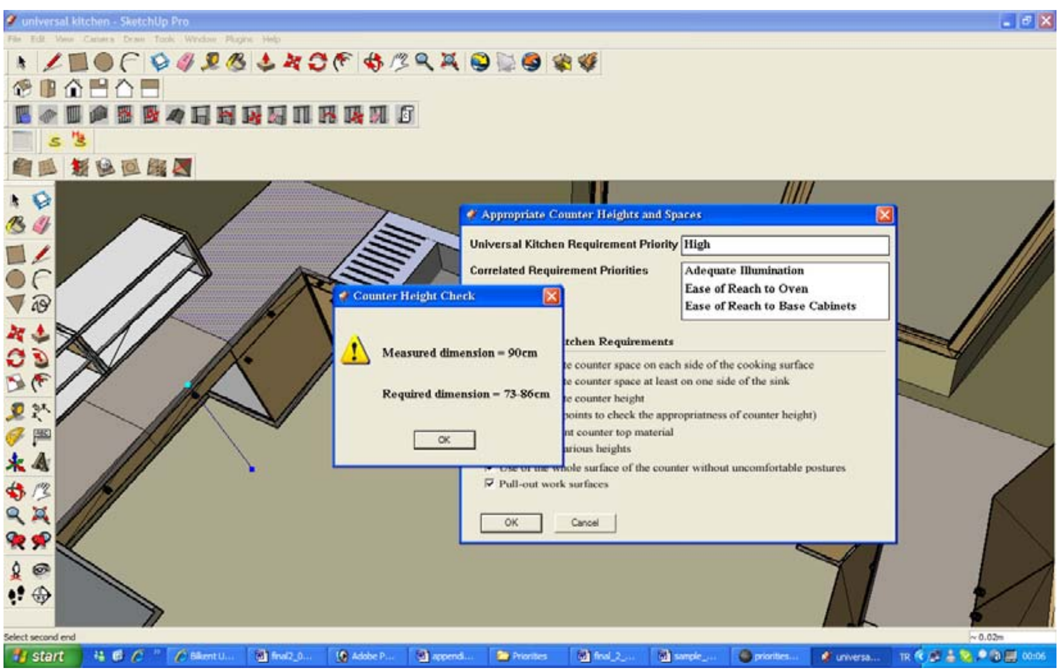


Figure 5.33. The dialog box displaying the appropriateness of the counter height.

#### 5.3.3.2 The ‘Universal Design Checklist’ Interface

In addition to the ‘Priority Check’ interface the ‘Universal Design Checklist’ interface is used for an overall evaluation of the completed kitchen solution to support design decisions and produce better kitchen designs. The interface design of the ‘Universal Design Checklist’ is explained in Chapter 3. The 3-D solution is evaluated against the seven principles of universal design by using a 2-point scale from ‘Yes’ to ‘No’. Rather than being a score sheet, the ‘Universal Design Checklist’ interface provides a type of graphic profile for design features that helps to identify a specific strength and weakness of the kitchen. It serves to evaluate how well the solution meets universal design principles. The features of the solution, which are marked as ‘No’, are reworked and redesigned to remove barriers for some potential users. As seen in Figure 5.34, if designers check ‘No’, the interface automatically pops up a dialog box, which prompts designers to go the related dimensional standard and/or design guideline to improve the feature.

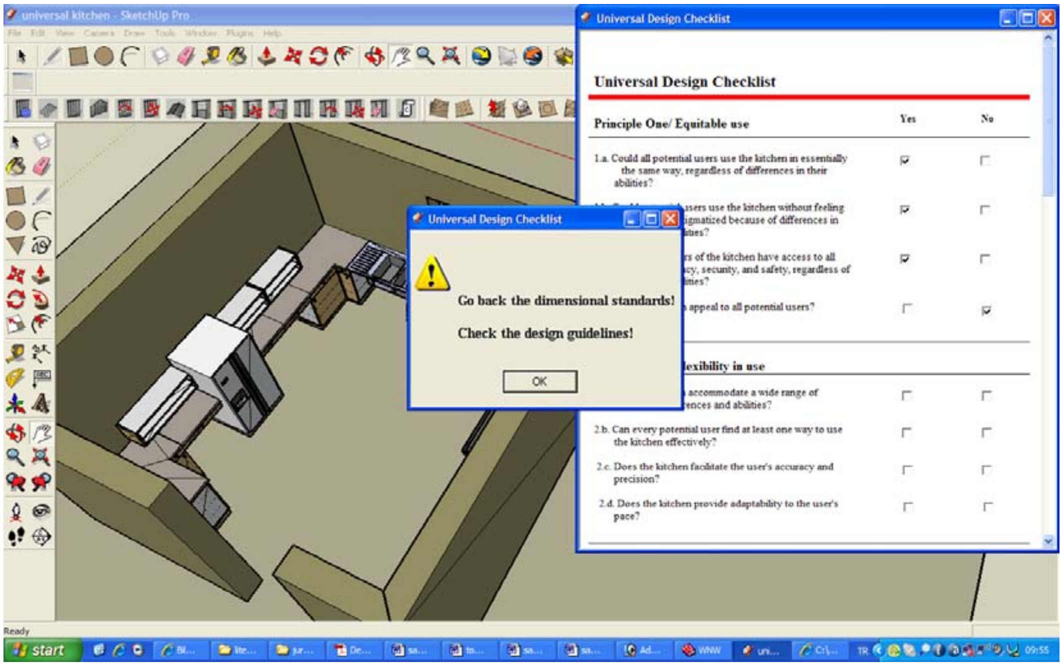


Figure 5.34. Evaluating the solution with the 'Universal Design Checklist' interface.

To summarize, the CAUD plug-in tool that is developed in three stages supports the conceptual design process of a universal kitchen by appropriate editing of graphical facilities, providing automated suggestions, memory supports and verbal/pictorial data. Through the plug-in tool, designers gain analysis/synthesis/evaluation feedback of requirement priorities that is both timely and relevant to their current design task. So, all the above explained facilities of the CAUD plug-in tool provide an essential basis for enhancing designers' cognitive approach to the universal design process and augmenting their universal design problem-solving abilities regarding each of the universal design requirement priority.

# 6. ASSESING THE USER ACCEPTANCE OF THE CAUD PLUG-IN TOOL

Users' acceptance of a computer-based information system is the crucial factor in determining the success or failure of the system (Lucas, 1975). Abundant literature suggests that systems can fail when the user's attitudes and reactions towards the system are ignored in the implementation process (Liker and Sindi, 1997). "Contemporary information technology (IT)-related research has focused on use or user acceptance as a key dependent measure for valuing IT" (Morris and Turner, 2001, p. 877). Through user acceptance studies, researchers gain descriptive information about successful IT, and information for better designing CAD systems and improving their utility. Therefore, in this chapter the assessment of the user acceptance of the CAUD plug-in tool is conducted. The study deals with the users' opinion about the plug-in tool's value as a new enabling tool, its usefulness, clarity, efficiency, support and satisfaction.

## 6.1 System Acceptance Questionnaire (SAQ)

Throughout the past decade, a variety of models and techniques on user acceptance assessment have been proposed to help, explain and predict user acceptance.

According to the literature, a user acceptance assessment technique should be simple, robust, theoretically based and generalizable (Liker and Sindi, 1997). Reviewing the contemporary human-computer interaction studies showed that there are many questionnaires that are developed to assess the user acceptance of a system or product (Chin et al., 1988; Davis, 1989; Lewis, 1995; Shneiderman, 1998). Since checking the reliability and validity of a questionnaire is a long term process, it advisable to use questionnaires that have been already tested and standardized by institutions as a result of comprehensive studies (Kirakowski, 2003). In addition to making the results of usability studies easier to interpret, using validated questionnaires that are relevant in the context investigated is important in terms of the success of usability evaluation. In this respect, this study adapted the 'System Acceptance Questionnaire' developed at HUSAT Research Institute (2001) to assess the user acceptance of the CAUD plug-in tool (See Appendix I).

The SAQ consists of three parts. First part contains 25 statements that are categorized under 5 constructs; usefulness, clarity, efficiency, support/help and satisfaction (Table 6.1). There are 5 statements under each construct. During the questionnaire, the participants are asked to consider and state their level of agreement with each statement by using a 7-point Likert scale ranged from 'strongly agree' (7) to 'strongly disagree' (1). The average response to each construct is the measure of each of the system acceptance. So, the collected data is used to generate scores for system acceptability. Following closed ended questions about the usefulness, clarity, efficiency, support/help and satisfaction, in the second part open ended questions are directed to identify the favourite functions of the plug-in tool, its missing characteristics and any problems faced during usage. In order to gather demographic information about participants, background questions are asked in the last part of the questionnaire.

Table 6.1. Constructs and their descriptions

| Construct | Statements | Description |
|---|---|---|
| Usefulness | 5 | The degree to which a person believes that using a particular system would enhance his or her performance (Davis, 1989). |
| Clarity | 5 | The degree to which a system provides clear and understandable ways of use (Nielsen, 1993). |
| Efficiency | 5 | The expended resources in relation to the accuracy and completeness with which users achieve goals (ISO 9241-11, 1998; Nielsen, 1993). |
| Support/help | 5 | The degree to which a system provides necessary help information that should be easy to search, focused on the user's task, and list concrete steps to be carried out (Nielsen, 1993). |
| Satisfaction | 5 | Freedom from discomfort, and positive attitude to the use of the product (ISO 9241-11, 1998; Nielsen, 1993). |

### 6.1.1 Methodology

First, data were collected by using the SAQ. Then, statistical analyses were conducted to evaluate the questionnaire data. Based on the analyses the CAUD plug-in tool acceptability is discussed. Finally, guidelines for future researches on CAD tools are drawn. The guidelines refer to the statements on how to construct a computational design environment with high acceptability scores.

#### 6.1.1.1 The Sample Group

A total of 20 respondents (11 male, 9 female) participated in the questionnaire. Respondents are recruited from an international architectural design company, which is officially using SketchUp software. So, all the respondents have prior SketchUp experience. The age range of respondents is between 25 and 52 years (mean: 35.55). Twelve of respondents are architects and eight of the respondents are interior architects. The demographic characteristics of the respondents are shown in Table 6.2.

Table 6.2. The demographic characteristics of the respondents

| Respondent No | Profession | Nationality | Age | Gender | | Education | SketchUp Experience |
|---|---|---|---|---|---|---|---|
| | | | | M | F | | |
| R1 | Architect | Libyan | 31 | X | | Master Degree | Above 3 Years |
| R2 | Architect | Brazil | 29 | | X | Master Degree | Above 3 Years |
| R3 | Architect | Libyan | 28 | | X | University | 1-3 Years |
| R4 | Architect | Libyan | 38 | | X | University | 1-3 Years |
| R5 | Architect | Libyan | 34 | | X | University | 1-3 Years |
| R6 | Architect | Libyan | 36 | X | | University | 1-3 Years |
| R7 | Architect | Libyan | 52 | X | | University | Below 1 Years |
| R8 | Architect | Portuguese | 40 | X | | Master Degree | Above 3 Years |
| R9 | Architect | Portuguese | 43 | X | | Master Degree | Above 3 Years |
| R10 | Architect | Portuguese | 37 | X | | University | 1-3 Years |
| R11 | Architect | Brazil | 28 | | X | University | 1-3 Years |
| R12 | Architect | Brazil | 32 | X | | University | 1-3 Years |
| R13 | Interior Architect | Brazil | 35 | X | | University | Below 1 Years |
| R14 | Interior Architect | Brazil | 48 | X | | University | Above 3 Years |
| R15 | Interior Architect | Brazil | 28 | | X | Master Degree | Above 3 Years |
| R16 | Interior Architect | Brazil | 43 | | X | Master Degree | Above 3 Years |
| R17 | Interior Architect | Portuguese | 31 | | X | University | Below 1 Years |
| R18 | Interior Architect | Portuguese | 33 | | X | University | 1-3 Years |
| R19 | Interior Architect | Portuguese | 29 | X | | University | 1-3 Years |
| R20 | Interior Architect | Portuguese | 36 | X | | University | 1-3 Years |

#### 6.1.1.2 The Procedure

Assessing the user acceptance of the plug-in tool is composed of three consecutive sessions that are conducted face-to-face and individually with each respondent. First, each respondent receives 20 minutes of training on how to use the web dialogs and the dialog boxes of the CAUD plug-in tool. They watch a demonstration video, which details the functionalities and capabilities of the tool.

In the second session, each respondent is provided with the CAUD plug-in tool to conduct task scenarios. The goal of the task scenarios is to practice the respondents a kitchen design through the plug-in tool. Since a successful universal kitchen design solution necessitates the consideration of each UKR with its sub-UKRs simultaneously, it is aimed to encourage them to experiment with the six derived UKRs and their related sub-UKRs. Working with any of the UKRs require participants to use the user interfaces and databases of the CAUD plug-in tool, to find and select appropriate menu options, and then to position and manipulate kitchen objects within the SketchUp drawing environment. In this respect, the task scenarios are related with the 'Appropriate Counter Heights and Spaces' and 'Ease of Reach to Base Cabinets' UKRs, which are correlated with each other and have more correlated requirements compared to the other UKRs, are provided each respondent.

Having been the plug-in tool installed into each respondent's own computer, they received a SketchUp kitchen project, which is an incomplete kitchen model that lacks the counter and base cabinets design. So, the six written task scenarios related with counter and base cabinet design are given (Table 6.3). In the first task, they have to write the tasks -T2, T3, T4, T5 and T6- as to-do list specifications. The second task is designing counters at appropriate heights and spaces. The third task is related with base cabinets design with appropriate dimensions (including a functional corner cabinet design). In the fourth and fifth task, the respondents have to manage with the relevant priority information on both counters and base cabinets. The sixth task is checking the appropriateness of the given kitchen design for the seven principles of universal design. The final task encourages each respondent to move around the interfaces of the plug-in tool by reworking the features of the model, which are marked as 'strongly agree' and/or 'strongly disagree'. No time restrictions are imposed on the respondents to complete the tasks.

Table 6.3. The task scenarios that are given to each respondent

| **Task Scenario** | **Description** |
|---|---|
| T1 | Write the tasks -T2, T3, T4, T5 and T6- as to-do list specifications |
| T2 | Design counters at appropriate heights and spaces |
| T3 | Design base cabinets with appropriate dimensions (including a functional corner cabinet design) |
| T4 | Manage with the relevant priority information on counters |
| T5 | Manage with the relevant priority information on base cabinets |
| T6 | Check the appropriateness of the kitchen for the seven principles of universal design |

The six task scenarios took the respondents approximately 80-100 minutes (See Figure 6.1 for an exemplary photo taken during the tasks). The author was present with the participants during the tasks, providing them with the task instructions and additional help when necessary. However, to avoid response biases, it was strictly forbidden to click menus or complete any transactions in lieu of the respondents. After the tasks are completed, participants are given the SAQ. It takes the respondents approximately 15-20 minutes to complete the questionnaire (See Figure 6.2 and 6.3 for exemplary photos taken during the questionnaires). In addition to the questionnaire data, the respondents are encouraged to think aloud, especially when they run into trouble or engage in a thought process. Furthermore, the observational data and respondents' comments about general use of the CAUD plug-in tool are also recorded to collect opinions that are not obtained from the questionnaire.

Figure 6.1. A respondent conducting the task scenario.

Figure 6.2. A respondent answering the questionnaire.

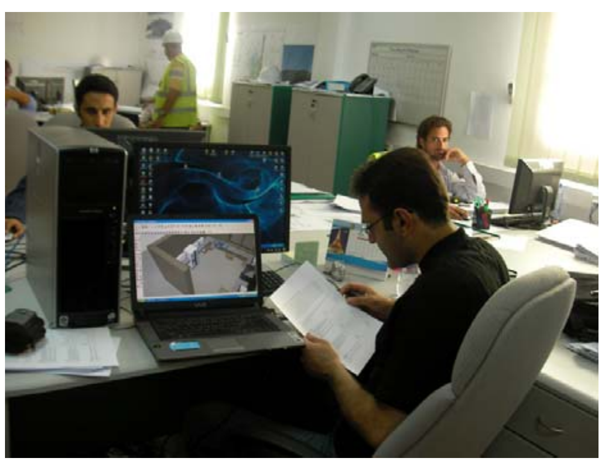

Figure 6.3. A respondent answering the questionnaire.

### 6.1.2 Findings

All respondents completed the tasks and filled the questionnaires. The results are presented below. The study first analyzed the responses to the close ended questions in part I and later, to open ended questions in part II.

#### 6.1.2.1 Analysis of the Acceptability Scores for the CAUD Plug-in Tool

In general, the scores show that the CAUD plug-in tool is acceptable (4 or above) on all the constructs (See Figure 6.4). It is scored well on the usefulness with an average score 5.44, clarity with an average score 5.71, efficiency with an average score 5.47, support/help with an average score 5.28 and satisfaction with an average score 5.94. The descriptive statistics for all the five constructs including their related statements is given in Table 6.4. For usefulness, except the statement "The plug-in tool does not really do what I want", for which the tool's score is below 4.0, the respondents found the facilities offered by the plug-in tool useful in supporting and enhancing universal kitchen design. The reason for the low score of this statement is that 12 of 20 respondents regardless their profession had difficulties in understanding what means value and what means cost. So, they did not found useful the information in the 'Priority Manager' interface and suggested when the cursor is on the value-cost information, an explanation tag would be beneficial that describes the meaning of value-cost. It would be so much easier to use the priority data if there were any explanations. However, half of the respondents strongly disagreed to design universal kitchens without the plug-in tool because they see a lot of advantages of using the plug-in tool, such as it saves time, gives relevant information within a CAD environment.

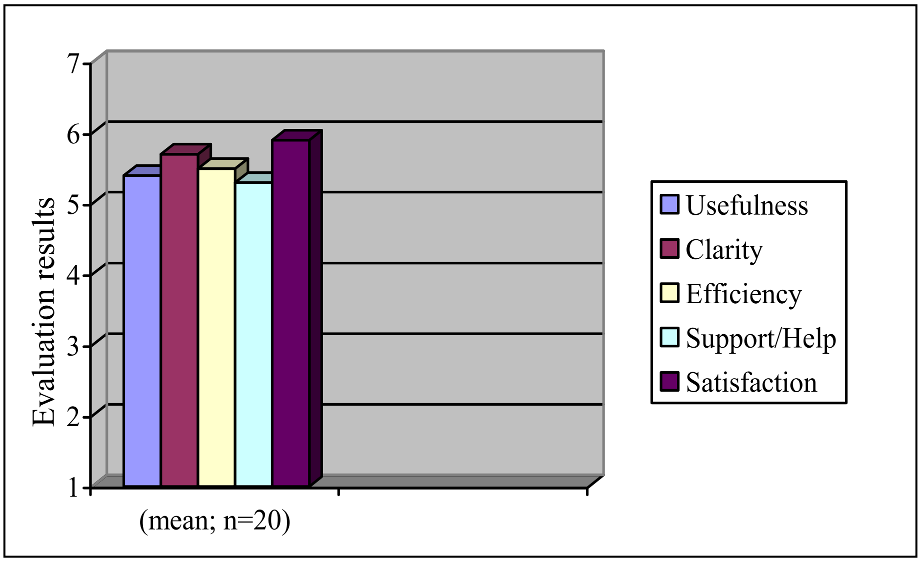


Figure 6.4. Results based on 7-point rating scales (min score=1, max score=7, mean score=4)

Table 6.4. Descriptive statistics for all the five constructs.

| Construct | Statement | Mean | S.D. | Average |
|---|---|---|---|---|
| Usefulness | US1 | 5.50 | 0.513 | 5.44 |
| | US2 | 6.25 | 0.716 | |
| | US3 | 5.45 | 0.686 | |
| | US4 | 6.15 | 0.812 | |
| | US5 | 3.85 | 1.136 | |
| Clarity | CL1 | 6.55 | 0.510 | 5.71 |
| | CL2 | 6.50 | 0.607 | |
| | CL3 | 4.60 | 0.598 | |
| | CL4 | 5.00 | 0.562 | |
| | CL5 | 5.90 | 0.307 | |
| Efficiency | EF1 | 5.70 | 0.470 | 5.47 |
| | EF2 | 5.55 | 0.510 | |
| | EF3 | 5.40 | 0.598 | |
| | EF4 | 5.45 | 0.510 | |
| | EF5 | 5.25 | 0.716 | |
| Support/Help | SU1 | 5.80 | 0.523 | 5.28 |
| | SU2 | 4.70 | 0.571 | |
| | SU3 | 5.10 | 0.552 | |
| | SU4 | 5.70 | 0.656 | |
| | SU5 | 5.10 | 0.552 | |
| Satisfaction | SA1 | 6.80 | 0.410 | 5.94 |
| | SA2 | 6.15 | 0.366 | |
| | SA3 | 6.05 | 0.825 | |
| | SA4 | 5.30 | 0.656 | |
| | SA5 | 5.40 | 0.680 | |

For clarity, the scores of all the statements are above 4 so that the plug-in tool was seen as a reasonably clear and understandable. Especially, the first two statements of clarity with the highest means (6.55 and 6.50) indicated that the structure of the interfaces is quite straightforward and respondents almost did not have any problems with the layout of the plug-in tool. Ten of the respondents answered these two statements with a 7 and reasoned that the information in the interfaces is expressed clearly and there is also the use of pictorial and colored texts that makes the data understandable. For efficiency, the mean values of the statements are close to each other. The results and observations showed that all the respondents achieved the given six tasks quickly within the SkecthUp environment. They experienced and moved around the various dialog boxes and web dialog boxes of the plug-in tool accurately. The lowest score was obtained for the fourth construct, support/help, because most of the respondents (15 of 20) want to see a help tutorial within the plug-in tool in order to overcome any problems easily and confidently. Thus, it is desirable to consider the development of a more comprehensive help system in the future. Among the five constructs, satisfaction has the highest mean value because 16 of 20 respondents answered the statements SA21 and SA23 with a 7. They were satisfied with the capabilities of the plug-in tool so that it would be interesting to learn and experience more about the tool.

Having calculated the acceptability scores of the plug-in tool, additional statistics were also performed to determine relationships between the acceptability scores of the five constructs and respondents' profession. Except clarity, there is no statistically significant relationship between the acceptability scores and professions. Concerning clarity, there is a statistically significant relationship between the architects and interior architects ($x^2$=13,857, df=4, $\alpha$=0, 01, two-tailed). Moreover, the study carried also the F-tests in order to analyze whether the acceptability score means of the architects were significantly different from the interior architects. The results indicated that there is a statistically significant difference between the architects and interior architects only in clarity among the five constructs (F=7.102, df=(1, 18), $p<0.01$). Different from architects, most of the interior architects (6 of 8) stated that it was not always obvious what to do next, especially in working with dimensional standards, design guidelines and catalog of solutions. For more clarity, they suggested that it would be necessary to be directed to the most recent web information and internet addresses for dimensional standards, guidelines and previous universal kitchen design solutions. There could be an embedded browser inside the plug-in tool, through which designers can open web pages and search answers to their questions.

#### 6.1.2.2 Analysis of the Respondents' Opinions

As seen in the statistical analyses, all the respondents have positive opinions about the CAUD plug-in tool. Besides the statements of acceptability scores, all the respondents answered also the open-ended questions. The most favourite function of the plug-in tool is described as the priority check by 10 of 20 respondents. They stated that it is an essential interface, through which it would possible to reduce error rates before the construction. Since the 'Priority check' interface allows to assess the design in different design stages, it is possible to improve designs before final decisions. Furthermore, the 'Critic list' interface, 'Dimensional standards' and 'Design guidelines' interfaces showed to be the other favourite functions of the plug-in tool. 4 of the 12 architects highlighted the importance of the critic list and its potential for various design projects in addition to kitchen design. Rather than the architects, 6 of 8 interior architects defined dimensional standards and design guidelines as the favourite functions of the plug-in tool because they can save a lot of time through these capabilities.

> *Respondent 16*
>
> *"'Priority check' interface helps to evaluate designs confidently and leave designers sure what and how to make changes to fulfil the requirements".*
>
> *Respondent 8*
>
> *"'Critic list' interface is an efficient solution for which we run into difficulties with collaborating our partner-designers in different countries.*
>
> *Respondent 13*
>
> *"With the capabilities of dimensional standards and design guidelines, it does not take time to finish a project. Since while drawing within the computational mediums, most of the time is spent on data collection about standards, specifications and guidelines".*

The respondents also stated their missed functions in the plug-in tool. According to 6 of 20 respondents, it would be beneficial to check the appropriateness of the appliances' dimensions and to be informed about maximum and minimum dimension requirements. They experienced difficulties on evaluating the appropriateness of dimensions of various design features and they would like to have a dimension check interface, similar to the priority check. 4 of the 20 respondents missed an active critic list option, in which designers would open up their critic list interface within the Sketchup software and actively make changes to the model in real time. This interface would enable each designer to instantly connect with other designers and collaborate with them on different parts of a project either by sending instant messages or making audio-video calls. Moreover, 6 of 20 respondents missed to see more universal design solutions and stated that it would be beneficial to include web pages links within the dialog boxes of dimensional standards, design guidelines and catalog of universal design solutions. According to the rest of the respondents (4 of 20) it would be great that designers could be able to add red bubbles or sticky notes for areas that need revisions.

*Respondent 5*

*"Please provide an extension of the priority check that makes it easier to evaluate the dimensions according to the required standards".*

*Respondent 11*

*"There would be a chat module within the critic list interface through which designers could collaborate synchronously".*

*Respondent 20*

*"I believe that a new web dialog with web pages links to some of the numerous available universal kitchen design solutions on the web is a good idea".*

Finally, the respondents also developed suggestions for further improvement of the plug-in tool. Most of the architects (9 of 12) suggested that the 'Universal design checklist' interface could be made more dynamic and interesting through the availability of calculating universal kitchen design performance. Having filled the universal design checklist, they would like to see the ratio information of yes/no questions, through which the tool could report the overall performance of a kitchen project in percentages. Then, with the resulting report it would be easier to compare the weaknesses or strengths of the project with other successful solutions. In doing this, they felt they would have more control of the plug-in tool. The other suggestion stated by the rest of the group is the need for further development of the plug-in tool for other built environments and interior spaces. Especially, all the interior architects (8 of 8) would like to see a developed version of this plug-in tool for bathrooms, which could help in the same way.

> *Respondent 2*
>
> *"The tool could be developed to include the ratio information of yes/no questions, through which the universal design performance of the kitchen solution could be calculated".*

> *Respondent 18*
>
> *"It would be great to have such a plug-in tool for other parts of a house, especially for a bathroom".*

## 6.2 Discussion

System acceptability assessment provides new insights into the way designers solve universal design problems within a CAD environment. The findings suggest that CAD developers should provide a working environment for designers where usefulness, clarity, efficiency, help and satisfaction are supported and fostered in order to facilitate successful universal design solutions easily beginning from conceptual design phases. Aside from the above acceptability issues, the respondents found the plug-in tool to be easy to master and use. They were comfortable with adopting new functions of the plug-in tool and eager for utilizing these functions to design universal interior spaces within the SketchUp environment. The need for more useful 'Priorty manager' interface is the main critical issue within acceptability of the plug-in tool. Most users found the 'Priority check' interface as the powerful feature of the plug-in tool.

Additionally, there is an effect of the respondents' profession on assessing the acceptability of the plug- in. Interior architects deal with good detailing and correct specification of interior design requirements of the plug-in tool, such as provision of detailed dimensional standard and design guidelines information, whereas architects are more concentrated on the success of the final solution, such as obtaining performance reports. In this respect, the results confirmed that achieving a successful CAUD plug-in tool necessitates the overall consideration of problem-solving requirements of different professions, such as architects, interior architects and industrial designers, since universal design touches every aspect of a built environment (Danford and Tauke, 2001). Furthermore, it is essential to provide the ability for simultaneous drawing on the same project and following the changes synchronously can be helpful to support online design since it is possible to develop solutions to the design problem as a team work. Moreover, a plug-in tool should be able to offer and update a variety of information that is easy to understand, flexible enough to move around, sufficient to provide support and also enjoyable to work with. While this acceptability study is useful in many aspects, it is also important that users should experience the CAUD plug-in tool for a longer period of time in an uncontrolled environment to make more detailed assessments and suggestions.

## 6.3 Guidelines for Future Researches on CAD Tools

The results of the study indicated that all the respondents had positive opinions about the plug-in tool and user satisfaction was high but there is certainly a possibility for improvement. Based on respondents' assessments and cognitive needs of designers, this study suggests some guidelines that will lead to better design solutions and will be helpful to develop such plug-in tools for other universally designed interior spaces and built environments (Table 6.5).

Table 6.5. Guidelines for CAD tools.

| **Guidelines** |
| --- |
| 1. The system should attain the simplest interface with the least number of menu options and suitable set of commands to access and manipulate the universal design data. |
| 2. The system should be flexible that allows customization of its interfaces according to the changing situations during the design process. |
| 3. The system should provide fast and intuitive ways to assist designers to define a set of objectives of a project. |
| 4. The system should provide the ability to enter requirements, design specifications from brief and other sources. |
| 5. The system should remind designers to finish the specifications that are in progress. |
| 6. The system should allow to modify/add/specify new ones to the initially stated specifications. |
| 7. The system should allow designers to easily and quickly extract the universal design data, such as dimensional standards, accessibility requirements, technical specifications, minimum code requirements of universal design and design guidelines. |

Table 6.5. Continued.

| | |
|---|---|
| 8. | The total time spent on decision making should be less. |
| 9. | The system should provide designers the possibility of richer interaction capabilities with other designers all over the world, such as instant messaging, video calling, during their divergent and convergent thinking activities. |
| 10. | The system should provide additional data links from up-to-date web-pages of universal design that can be useful for generating solution alternatives. |
| 11. | The system should have a critic-based approach that provides the basis for decision-making process of designers during synthesis. |
| 12. | The system should not interrupt designer's creative process, i.e. should not design instead of designer. |
| 13. | The system should provide more user friendly menus including auditory, pictorial and textual data of universal design that can contain images and sketches with necessary annotations and descriptions. |
| 14. | The system should provide designers the ability to input/edit/delete the universal design requirements and/or add new requirements including their priority weights according to value, cost, time and/or other tradeoffs. |
| 15. | The system should provide means through which designers can evaluate solution alternatives both during the universal design process and at the end of the universal design process. |
| 16. | The system should give designers the opportunity to add sticky notes and comment boxes through which the consequences of design evaluations can be shown for later referencing, comparison and backtracking. |
| 17. | The system should provide rapid feedbacks regarding the requirement priorities to check the satisfaction degrees of each requirement priority. |
| 18. | The system should report the universal design performance of the final solution to achieve the most satisfactory solution that meets better universal design priorities. |
| 19. | The total time spent on evaluating developed design alternatives should be less through the system. |

# 7. CONCLUSION

The objective of this thesis is to develop and implement a (CAUD) plug-in tool for the conceptual phase of universal design process. The plug-in tool aims to assist designers in creating universally designed kitchens. Based on this concept, the CAUD plug-in tool is constructed within the framework of SketchUp software. With the three environments, modeling, application language and universal design, that are written by SketchUp Ruby API, the plug-in tool focuses on an understanding of universal design process, in which the overall form, size and appearance of kitchens are set based on a knowledge domain and kitchen features are defined and checked against to pre-defined requirement priorities and their correlations. In this respect, this proposed CAUD plug-in tool serves as a design medium for conceptual universal design operations of designers rather than an expensive drafting tool like in traditional CAD systems.

Universal design process is composed of a series of goal oriented cognitive activities. Although the final goal is ill-defined at the beginning, the subgoals have to be well-defined throughout the design process by the cognitive abilities of the designer (Akin, 1986; Cross; 2006; Lawson, 1990). So to be able to create successfully universal design solutions, designers should be supported by CAD systems consistent with their cognitive design strategies. However, having reviewed the current CAD literature, a limited amount of work was found that has attempted to provide the use of computer-based universal design tools in supporting the development of universal products and environments. Especially, designers fail to handle the conceptual design activities, in which the use of CAD tools is misdirected or poorly fitted to the requirements and cognitive needs of designers. So, the thesis analyzed the problem-solving process of universal design based on the ideal cognitive design strategy of designers and constructed the capabilities of the CAUD plug-in tool. The tool capabilities and their interfaces are motivated by a proposed cognitive strategy, multiple divergence-convergence based design strategy, for the conceptual phase of universal design problem-solving process.

The plug-in tool is composed of six interface designs: ‘To-Do List’ for analysis; ‘Dimensional Standards’, ‘Design Guidelines’, ‘Critics List’ and ‘Catalog of Universal Kitchen Design Solutions’ for synthesis; ‘Priority Check’ and ‘Universal Design Checklist’ for evaluation. Moreover, there is also a ‘Priority Manager’ interface, whose data is obtained through a hybrid prioritization technique that is proposed in Chapter 5. By storing in and retrieving the relative universal kitchen priorities from the ‘Priority Manager’ interface, the designer has the opportunity of correcting actions in analyzing, generating and evaluating satisfactory universal design solutions under conditions of certainty. The relationship of the priority manager with the capabilities of the plug-in tool can be explained as an essential interaction activity, when user needs are diverse, design requirements multi-attribute, timelines short, budget limited.

As Demirkan (2007) stated, systematic presentation and manipulation of universal design requirement priorities are essential for the success of universal design practice. Regarding this challenge, the CAUD plug-in tool provides an effective systematic support in selecting the right set of requirements for implementation and assisting to resolve the conflicts between requirement priorities. Designers can easily decide on the importance degrees of universal design data through the ‘Priority Manager’ and ‘Priority Check’ interfaces rather than failing to meet the universal design requirements or tackling with those requirements in the final detailing phases in design process. In this respect, the plug-in tool can encourage designers to create promising universal design solutions within a CAD environment from the onset of a design process. However, as stated by Meniru et al. (2003) that managing design process should not be left to the computer but the designer, within the CAUD plug-in tool environment the final decision is left to the designer. All the changes and/or ideas introduced automatically by the plug-in tool must be examined and acknowledged by the designer before inclusion in the design. In this respect, the interaction activities of designer with the plug-in tool cycle until the designer is satisfied with the output.

The results of the acceptability studies indicated that in general the CAUD plug-in tool is found useful, understandable, efficient, helpful and satisfactory to support and foster successful universal design solutions. All the suggested recommendations, which are done in Chapter 7, are beneficial to support an ideal universal design problem-solving process and increase the user acceptance of CAD tools that are aimed to be used during this process. In this respect, the thesis has the following benefits and contributions to the literature:

(1) The universal design knowledge domain is interfaced with the computational design tools.

(2) The limitations in the universal design practice are overcome by providing the best balance between the two conflicting design goals; generation of universal design concepts that go beyond the possible range and the evaluation of a limited number of alternative design solutions.

(3) The cognitive aspects of the universal design operations are facilitated to respond to the needs of designers within a CAD environment.

(4) Requirement–design relationships are computed successfully by presenting the cost-value ratios of requirement priorities and checking the solution alternatives against to the predefined priorities.

However, the study was restricted by financial and technical base. Future studies would involve an advanced CAUD plug-in tool that is based on more flexible and advanced design, drafting and communication technologies with improved features for interface designs. In that case, it would be also possible to extend the capabilities of the plug-in tool for other interior spaces, especially for bathrooms as suggested by the respondents, who carried out the acceptability studies.

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# APPENDICES

# APPENDIX A. The Analytic Hierachy Process (AHP)

## THE ANALYTIC HIERARCHY PROCESS

To make decisions, you identify, analyze, and make tradeoffs between different alternatives to achieve an objective. The more efficient the means for analyzing and evaluating the alternatives, the more likely you'll be satisfied with the outcome. To help you make decisions, the Analytic Hierachy Process compares alternatives in a stepwise fashion and measures their contribution to your objective.[1]

**AHP in action.** Using AHP for decision making involves four steps. We'll assume here that you want to evaluate candidate requirements using the criterion of value.

**Step 1.** *Set up the* n *requirements in the rows and columns of an* $n \times n$ *matrix.* We'll assume here that you have four candidate requirements: Req1, Req2, Req3, and Req4, and you want to know their relative value. Insert the $n$ requirements into the rows and columns of a matrix of order $n$ (in this case we have a $4 \times 4$ matrix).

**Step 2.** *Perform pairwise comparisons of all the requirements according to the criterion.* The fundamental scale used for this purpose is shown in Table A.[1] For each pair of requirements (starting with Req1 and Req2, for example) insert their determined relative intensity of value in the position (Req1, Req2) where the row of Req1 meets the column of Req2. In position (Req2, Req1) insert the reciprocal value, and in all positions in the main diagonal insert a "1." Continue to perform pairwise comparisons of Req1–Req3, Req1–Req4, Req2–Req3, and so on. For a matrix of order $n$, $n \cdot (n-1)/2$ comparisons are required. Thus, in this example, six pairwise comparisons are required; they might look like this:

| | Req1 | Req2 | Req3 | Req4 |
|---|---|---|---|---|
| **Req1** | 1 | 1/3 | 2 | 4 |
| **Req2** | 3 | 1 | 5 | 3 |
| **Req3** | 1/2 | 1/5 | 1 | 1/3 |
| **Req4** | 1/4 | 1/3 | 3 | 1 |

**Step 3.** *Use averaging over normalized columns to estimate the eigenvalues of the matrix* (which represent the criterion distribution). Thomas Saaty proposes a simple method for this, known as averaging over normalized columns.[1] First, calculate the sum of the $n$ columns in the comparison matrix. Next, divide each element in the matrix by the sum of the column the element is a member of, and calculate the sums of each row:

| | Req1 | Req2 | Req3 | Req4 | *Sum* |
|---|---|---|---|---|---|
| **Req1** | 0.21 | 0.18 | 0.18 | 0.48 | *1.05* |
| **Req2** | 0.63 | 0.54 | 0.45 | 0.36 | *1.98* |
| **Req3** | 0.11 | 0.11 | 0.09 | 0.04 | *0.34* |
| **Req4** | 0.05 | 0.18 | 0.27 | 0.12 | *0.62* |

Then normalize the sum of the rows (divide each row sum with the number of requirements). The result of this computation is referred to as the *priority matrix* and is an estimation of the eigenvalues of the matrix.

$$\frac{1}{4} \cdot \begin{pmatrix} 1.05 \\ 1.98 \\ 0.34 \\ 0.62 \end{pmatrix} = \begin{pmatrix} 0.26 \\ 0.50 \\ 0.09 \\ 0.16 \end{pmatrix}$$

**Step 4.** *Assign each requirement its relative value based on the estimated eigenvalues.* From the resulting eigenvalues of the comparison matrix, the following information can be extracted:

- Req1 contains 26 percent of the requirements' total value,
- Req2 contains 50 percent,
- Req3 contains 9 percent, and
- Req4 contains 16 percent.

**Result consistency.** If we were able to determine precisely the relative value of all requirements, the eigenvalues would be perfectly consistent. For instance, if we determine that Req1 is much more valuable than Req2, Req2 is somewhat more valuable than Req3, and Req3 is slightly more valuable than Req1, an inconsistency has occurred and the result's accuracy is decreased. The redundancy of the pairwise comparisons makes the AHP much less sensitive to judgment errors; it also lets you measure judgment errors by calculating the consistency index of the comparison matrix, and then calculating the consistency ratio.

**Consistency index.** The consistency index (CI) is a first indicator of result accuracy of the pairwise comparisons. You calculate it as $CI = (\lambda \max - n)/(n-1)$. $\lambda \max$ denotes the maximum principal eigenvalue of the comparison matrix. The closer the value of $\lambda \max$ is to $n$ (the number of requirements), the smaller the judgmental errors and thus the more consistent the result. To estimate $\lambda \max$, you first multiply the comparison matrix by the priority vector:

$$\begin{pmatrix} 1 & 1/3 & 2 & 4 \\ 3 & 1 & 5 & 3 \\ 1/2 & 1/5 & 1 & 1/3 \\ 1/4 & 1/3 & 3 & 1 \end{pmatrix} \cdot \begin{pmatrix} 0.26 \\ 0.50 \\ 0.09 \\ 0.16 \end{pmatrix} = \begin{pmatrix} 1.22 \\ 2.18 \\ 0.37 \\ 0.64 \end{pmatrix}$$

Then you divide the first element of the resulting vector by the first element in the priority vector, the second element of the resulting vector by the second element in the priority vector, and so on:

$$\begin{pmatrix} 1.22 / 0.26 \\ 2.18 / 0.50 \\ 0.37 / 0.09 \\ 0.64 / 0.16 \end{pmatrix} = \begin{pmatrix} 4.66 \\ 4.40 \\ 4.29 \\ 4.13 \end{pmatrix}$$

To calculate $\lambda$ max , average over the elements in the resulting vector:

$$\lambda \max = \frac{4.66+4.40+4.29+4.13}{4} = 4.37$$

Now the consistency index can be calculated:

$$CI = \frac{\lambda \max - n}{n-1} = \frac{4.37-4}{4-1} = 0.12$$

To find out if the resulting consistency index (CI = 0.12) is acceptable, you must calculate the consistency ratio.

**Consistency ratio.** The consistency indices of randomly generated reciprocal matrices from the scale 1 to 9 are called the random indices, RI.[1] The ratio of CI to RI for the same-order matrix is called the consistency ratio (CR), which defines the accuracy of the pairwise comparisons. The RI for matrices of order $n$ are given below. The first row shows the order of the matrix, and the second the corresponding RI value.

| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |

According to Table A, the RI for matrices of order 4 is 0.90. Thus, the consistency ratio for our example is

$$CR = \frac{CI}{RI} = \frac{0.12}{0.90} = 0.14 .$$

As a general rule, a consistency ratio of 0.10 or less is considered acceptable.[1] This means that our result here is less than ideal. In practice, however, consistency ratios exceeding 0.10 occur frequently.

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**TABLE A**
**SCALE FOR PAIRWISE COMPARISONS**

| **Relative intensity** | **Definition** | **Explanation** |
|---|---|---|
| 1 | Of equal value | Two requirements are of equal value |
| 3 | Slightly more value | Experience slightly favors one requirement over another |
| 5 | Essential or strong value | Experience strongly favors one requirement over another |
| 7 | Very strong value | A requirement is strongly favored and its dominance is demonstrated in practice |
| 9 | Extreme value | The evidence favoring one over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between two adjacent judgments | When compromise is needed |
| Reciprocals | If requirement $i$ has one of the above numbers assigned to it when compared with requirement $j$, then $j$ has the reciprocal value when compared with $i$. | |

# APPENDIX B. The Survey Instrument

This survey aims to identify the kitchen needs of diverse user groups (adult, elderly, people with physical and visual disabilities). It lists the design features for a kitchen. Please rate your importance level for each feature on a scale of 1-5, (1 being the least important and 5 the most important) and mark the appropriate boxes to identify how important is each of the following features in working successfully within a kitchen environment.

**Age:** **Disability type:**

**Gender:** Female ☐ Male ☐ **Education level:**

**User group:** Adult ☐ Elderly ☐ Disabled ☐

| **A. Circulation** | Least Important **1** | **2** | **3** | **4** | Most Important **5** |
|---|---|---|---|---|---|
| 1. Ease of moving/manoeuvring in the kitchen | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. An adequate clear floor area if more than one person using the kitchen | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. An uninterrupted clear floor area of the work triangle between the refrigerator, sink and cooking | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. Non-exhausting walking distances (the work triangle) between the refrigerator, sink and cooking surface | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. An adequate clearance at the three sides of the dining table | ☐ | ☐ | ☐ | ☐ | ☐ |

| **B. Cabinets and Storage Areas** | Least Important **1** | **2** | **3** | **4** | Most Important **5** |
|---|---|---|---|---|---|
| 6. Close approach to the cabinets | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7. Ease of reach to the low portions of the base cabinets | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8. Ease of reach to the high portions of the wall cabinets | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9. Ease of use of the rear portions of the base cabinets | ☐ | ☐ | ☐ | ☐ | ☐ |
| 10. Ease of use of the rear portions of the wall cabinets | ☐ | ☐ | ☐ | ☐ | ☐ |
| 11. Cabinets having pull-out shelves | ☐ | ☐ | ☐ | ☐ | ☐ |
| 12. Effective end efficient use of corner cabinets by 360° rotating mechanisms/lazy-susan units/moon swing-out shelves. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 13. Removable base cabinet doors | ☐ | ☐ | ☐ | ☐ | ☐ |
| 14. Use of the cabinet door handles with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 15. Use of the drawers and its contents without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |

| C. Counters/Work Surfaces | Least Important 1 | 2 | 3 | 4 | Most Important 5 |
|---|---|---|---|---|---|
| 16. Close approach to the counter | ☐ | ☐ | ☐ | ☐ | ☐ |
| 17. An appropriate counter height | ☐ | ☐ | ☐ | ☐ | ☐ |
| 18. Use of the whole surface of the counter without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 19. Counters at various heights | ☐ | ☐ | ☐ | ☐ | ☐ |
| 20. Pull-out work surfaces | ☐ | ☐ | ☐ | ☐ | ☐ |
| 21. An appropriate counter space at least on one side of the refrigerator | ☐ | ☐ | ☐ | ☐ | ☐ |
| 22. An appropriate counter space on each side of the cooking surface | ☐ | ☐ | ☐ | ☐ | ☐ |
| 23. An appropriate counter space at least on one side of the oven at the same level as the rack | ☐ | ☐ | ☐ | ☐ | ☐ |
| 24. An appropriate counter space at least on one side of the sink | ☐ | ☐ | ☐ | ☐ | ☐ |
| 25. Rounded edges on the counter | ☐ | ☐ | ☐ | ☐ | ☐ |
| **D. Appliances** | Least Important **1** | **2** | **3** | **4** | Most Important **5** |
| 26. Close approach to the refrigerator | ☐ | ☐ | ☐ | ☐ | ☐ |
| 27. Ease of reach to all the essential elements of the refrigerator from the positions where the person would like to be in. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 28. Availability of warning features of the refrigerator about potential hazards | ☐ | ☐ | ☐ | ☐ | ☐ |
| 29. Close approach to the cook-top | ☐ | ☐ | ☐ | ☐ | ☐ |
| 30. Ease of reach to all the essential elements of the cook-top from the positions where the person would like to be in | ☐ | ☐ | ☐ | ☐ | ☐ |
| 31. Availability warning features of the cook-top about potential hazards | ☐ | ☐ | ☐ | ☐ | ☐ |
| 32. Close approach to the oven | ☐ | ☐ | ☐ | ☐ | ☐ |
| 33. Ease of reach to all the essential elements of the oven from the positions where the person would like to be in | ☐ | ☐ | ☐ | ☐ | ☐ |
| 34. Availability warning features of the oven about potential hazards | ☐ | ☐ | ☐ | ☐ | ☐ |
| 35. Close approach to the dishwasher | ☐ | ☐ | ☐ | ☐ | ☐ |
| 36. Ease of reach to all the essential elements of the dishwasher from the positions where the person would like to be in | ☐ | ☐ | ☐ | ☐ | ☐ |
| 37. Availability of warning features of the dishwasher about potential hazards | ☐ | ☐ | ☐ | ☐ | ☐ |
| 38. Close approach to the hood | ☐ | ☐ | ☐ | ☐ | ☐ |
| 39. Ease of reach to all the essential elements of the hood from the positions where the person would like to be in | ☐ | ☐ | ☐ | ☐ | ☐ |

| D. Appliances | Least Important 1 | 2 | 3 | 4 | Most Important 5 |
|---|---|---|---|---|---|
| 40. Availability of warning features of the hood about potential hazards | ☐ | ☐ | ☐ | ☐ | ☐ |

| E. Sink and Faucets | Least Important 1 | 2 | 3 | 4 | Most Important 5 |
|---|---|---|---|---|---|
| 41. Close approach to the sink | ☐ | ☐ | ☐ | ☐ | ☐ |
| 42. Use of the sink without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 43. Ease of reach to the faucet from the positions where the person would like to be in. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 44. Simplicity in operating the faucet | ☐ | ☐ | ☐ | ☐ | ☐ |
| 45. Operation of the faucet with less force | ☐ | ☐ | ☐ | ☐ | ☐ |

| F. Controls (Receptacles, switches and appliance controls) | Least Important 1 | 2 | 3 | 4 | Most Important 5 |
|---|---|---|---|---|---|
| 46. Close approach to the receptacles | ☐ | ☐ | ☐ | ☐ | ☐ |
| 47. Operation of the receptacles with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 48. Operation of the receptacles without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 49. Operation of the receptacles without sight | ☐ | ☐ | ☐ | ☐ | ☐ |
| 50. Close approach to the switches | ☐ | ☐ | ☐ | ☐ | ☐ |
| 51. Operation of the switches with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 52. Operation of the switches without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 53. Operation of the switches without sight | ☐ | ☐ | ☐ | ☐ | ☐ |
| 54. Close approach to the refrigerator controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 55. Simplicity in operating the refrigerator controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 56. Provision of helpful feedbacks by the refrigerator controls as the person use it. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 57. Operation of the refrigerator controls with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 58. Operation of the refrigerator controls without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 59. Close approach to the cook-top controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 60. Simplicity in operating the cook-top controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 61. Provision of helpful feedbacks by the cook-top controls as the person use it. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 62. Operation of the cook-top controls with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 63. Operation of the cook-top controls without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 64. Close approach to the oven controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 65. Simplicity in operating the oven controls | ☐ | ☐ | ☐ | ☐ | ☐ |

| **F. Controls (Receptacles, switches and appliance controls)** | Least Important **1** | **2** | **3** | **4** | Most Important **5** |
|---|---|---|---|---|---|
| 66. Provision of helpful feedbacks by the oven controls as the person use it | ☐ | ☐ | ☐ | ☐ | ☐ |
| 67. Operation of the oven controls with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 68. Operation of the oven controls without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 69. Close approach to the dishwasher controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 70. Simplicity in operating the dishwasher controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 71. Provision of helpful feedbacks by the dishwasher controls as the person use it | ☐ | ☐ | ☐ | ☐ | ☐ |
| 72. Operation of the dishwasher controls with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 73. Operation of the dishwasher controls without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| 74. Close approach to the hood controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 75. Simplicity in operating the hood controls | ☐ | ☐ | ☐ | ☐ | ☐ |
| 76. Provision of helpful feedbacks by the hood controls as the person use it | ☐ | ☐ | ☐ | ☐ | ☐ |
| 77. Operation of the hood controls with less force | ☐ | ☐ | ☐ | ☐ | ☐ |
| 78. Operation of the hood controls without uncomfortable postures | ☐ | ☐ | ☐ | ☐ | ☐ |
| **G. Illumination** | Least Important **1** | **2** | **3** | **4** | Most Important **5** |
| 79. Adequate natural light in the kitchen | ☐ | ☐ | ☐ | ☐ | ☐ |
| 80. Adequate artificial light in the kitchen | ☐ | ☐ | ☐ | ☐ | ☐ |
| 81. Adequate illumination levels over the working surfaces | ☐ | ☐ | ☐ | ☐ | ☐ |
| 82. Adequate illumination levels above the cook-top | ☐ | ☐ | ☐ | ☐ | ☐ |
| **H. Materials** | Least Important **1** | **2** | **3** | **4** | Most Important **5** |
| 83. A colour contrast between floor and counter material | ☐ | ☐ | ☐ | ☐ | ☐ |
| 84. A heat-resistant counter top material | ☐ | ☐ | ☐ | ☐ | ☐ |
| 85. A durable floor material | ☐ | ☐ | ☐ | ☐ | ☐ |
| 86. An easy-care floor material | ☐ | ☐ | ☐ | ☐ | ☐ |
| 87. A slip-resistant floor material | ☐ | ☐ | ☐ | ☐ | ☐ |

# APPENDIX C. The Detailed List of the 6 Factors with Their Corresponding Items and the Factor Loadings

**Factor 2- Appropriate Counter Heights and Spaces**

**Q17.** An appropriate counter height (0.805).

**Q19.** Counters at various heights (0.775).

**Q84.** A heat-resistant counter top material (0.769).

**Q18.** Use of the whole surface of the counter without uncomfortable postures (0.730).

**Q20.** Pull-out work surfaces (0.717).

**Q22.** An appropriate counter space on each side of the cooking surface (0.713).

**Q24.** An appropriate counter space at least on one side of the sink (0.712).

**Factor 3- Operation of Controls with Perceptible Information**

**Q56.** Provision of helpful feedbacks by the refrigerator controls as the person use it (0.948).

**Q66.** Provision of helpful feedbacks by the oven controls as the person use it (0.939).

**Q76.** Provision of helpful feedbacks by the hood controls as the person use it (0.916).

**Q61.** Provision of helpful feedbacks by the cook-top controls as the person use it (0.909).

**Q28.** Availability of warning features of the refrigerator about potential hazards (0.876).

**Q37.** Availability of warning features of the dishwasher about potential hazards (0.871).

**Q31.** Availability of warning features of the cook-top about potential hazards (0.771).

**Q25.** Rounded edges on the counter (0.721).

**Factor 1- Operation of Controls with Less Force**

**Q45.** Operation of the faucet with less force (0.952).

**Q57.** Operation of the refrigerator controls with less force (0.949).

**Q55.** Simplicity in operating the refrigerator controls (0.948).

**Q62.** Operation of the cook-top controls with less force (0.931).

**Q44.** Simplicity in operating the faucet (0.917).

**Q14.** Use of the cabinet door handles with less force (0.914).

**Q60.** Simplicity in operating the cook-top controls (0.909).

**Q47.** Operation of the receptacles with less force (0.858).

**Q51.** Operation of the switches with less force (0.831).

**Q67.** Operation of the oven controls with less force (0.811).

**Q65.** Simplicity in operating the oven controls (0.800).

**Factor 4- Adequate Illumination**

**Q81.** Adequate illumination level over the working surfaces (0.895).

**Q82.** Adequate illumination level above the cook-top (0.890).

**Q80.** Adequate artificial light in the kitchen (0.822).

**Q79.** Adequate natural light in the kitchen (0.767).

**Factor 5- Ease of Reach to Oven**

**Q33.** Ease of reach to all the essential elements of the oven from the positions where the person would like to be in (0.778).

**Q23.** An appropriate counter space at least on one side of the oven at the same level as the rack (0.731).

**Q32.** Close approach to the oven (0.723).

**Factor 6- Ease of Reach to Base Cabinets**

**Q7.** Ease of reach to the low portions of the base cabinets (0.834).

**Q9.** Ease of use of the rear portions of the base cabinets (0.821).

**Q12.** Effective end efficient use of corner cabinets by 360° rotating mechanisms/lazy-susan units/moon swing-out shelves (0.752).

## APPENDIX D. Principles and Guidelines of Universal Design

| Principles | Description and Guidelines |
|---|---|
| 1. Equitable use | The design is useful and marketable to people with diverse abilities.<br>1a. Provide the same means of use for all users: identical whenever possible; equivalent when not.<br>1b. Avoid segregating or stigmatizing any users.<br>1c. Provisions for privacy, security, and safety should be equally available to all users.<br>1d. Make the design appealing to all users. |
| 2. Flexibility in use | The design accommodates a wide range of individual preferences and abilities.<br>2a. Provide choice in methods of use.<br>2b. Accommodate right- or left-handed access and use.<br>2c. Facilitate the user's accuracy and precision.<br>2d. Provide adaptability to the user's pace. |
| 3. Simple and intuitive use | Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.<br>3.a. Eliminate unnecessary complexity.<br>3.b. Be consistent with user expectations and intuition.<br>3.c. Accommodate a wide range of literacy and language skills.<br>3.d. Arrange information consistent with its importance.<br>3.e. Provide effective prompting and feedback during and after task completion. |
| 4. Perceptible information | The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.<br>4a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.<br>4b. Provide adequate contrast between essential information and its surroundings.<br>4c. Maximize "legibility" of essential information.<br>4d. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).<br>4e. Provide compatibility with a variety of techniques or devices used by people with sensory limitations. |
| 5. Tolerance for error | The design minimizes hazards and the adverse consequences of accidental or unintended actions.<br>5a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded.<br>5b. Provide warnings of hazards and errors.<br>5c. Provide fail safe features.<br>5d. Discourage unconscious action in tasks that require vigilance |

## Appendix D. Continued.

| Principles | Description and Guidelines |
|---|---|
| 6. Low physical effort | The design can be used efficiently and comfortably and with a minimum of fatigue.<br>6.a. Allow user to maintain a neutral body position.<br>6.b. Use reasonable operating forces.<br>6.c. Minimize repetitive actions.<br>6.d. Minimize sustained physical effort. |
| 7. Size and space for approach and use | Appropriate size and space is provided for approach, reach, manipulation, and use, regardless of the user's body size, posture, or mobility.<br>7.a. Provide a clear line of sight to important elements for any seated or standing user.<br>7.b. Make reach to all components comfortable for any seated or standing user.<br>7.c. Accommodate variations in hand and grip size.<br>7.d. Provide adequate space for the use of assistive devices or personal assistance. |

<u>**APPENDIX E. The PG Cards**</u>

| |
|---|
| **Factor 1- Operation of Controls with Less Force** |
| **High** ☐ **Medium** ☐ **Low** ☐ |

| |
|---|
| **Factor 2- Appropriate Counter Heights and Spaces** |
| **High** ☐ **Medium** ☐ **Low** ☐ |

| |
|---|
| **Factor 3- Operation of Controls with Perceptible Information** |
| **High** ☐ **Medium** ☐ **Low** ☐ |

| |
|---|
| **Factor 4- Adequate Illumination** |
| **High** ☐ **Medium** ☐ **Low** ☐ |

| |
|---|
| **Factor 5- Ease of Reach to Oven** |
| **High** ☐ **Medium** ☐ **Low** ☐ |

| |
|---|
| **Factor 6- Ease of Reach to Base Cabinets** |
| **High** ☐ **Medium** ☐ **Low** ☐ |

# APPENDIX F. Pair-wise Comparison Sheets of 1-5 Point Scale for Value

## Appendix F.1 Pair-wise Comparison Sheets of the Six UKRs

Which of the two requirements is more valuable to you?

| | **5** | **4** | **3** | **2** | **1** | **2** | **3** | **4** | **5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| Operation of Controls with Less Force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Appropriate Counter Heights and Spaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of Controls with Perceptible Information |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate Illumination |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Oven |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Base Cabinets |
| Appropriate Counter Heights and Spaces | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of Controls with Perceptible Information |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate Illumination |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Oven |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Base Cabinets |
| Operation of Controls with Perceptible Information | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate Illumination |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Oven |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Base Cabinets |
| Adequate Illumination | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Oven |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Base Cabinets |
| Ease of Reach to Oven | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of Reach to Base Cabinets |

## Appendix F.2 Pair-wise Comparison Sheets of All the Sub-UKRs

Which of the two requirements is more valuable to you?

**Factor I- Operation of Controls with Less Force**

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Operation of the faucet with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the refrigerator controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the refrigerator controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the cook-top controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the faucet |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the cabinet door handles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Operation of the refrigerator controls with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the refrigerator controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the cook-top controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the faucet |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the cabinet door handles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |

| | **5** | **4** | **3** | **2** | **1** | **2** | **3** | **4** | **5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| Simplicity in operating the refrigerator controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the cook-top controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the faucet |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the cabinet door handles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Operation of the cook-top controls with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the faucet |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the cabinet door handles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Simplicity in operating the faucet | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Use of the cabinet door handles with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Use of the cabinet door handles with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Simplicity in operating the cook-top controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the receptacles with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Operation of the receptacles with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the switches with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Operation of the switches with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Operation of the oven controls with less force |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |
| Operation of the oven controls with less force | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Simplicity in operating the oven controls |

## Factor 2- Appropriate Counter Heights and Spaces

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| An appropriate counter height | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Counters at various heights |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | A heat-resistant counter top material |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the whole surface of the counter without uncomfortable postures |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Pull-out work surfaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space on each side of the cooking surface |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the sink |
| Counters at various heights | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | A heat-resistant counter top material |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the whole surface of the counter without uncomfortable postures |

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| An appropriate counter height | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Pull-out work surfaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space on each side of the cooking surface |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the sink |
| Counters at various heights | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Use of the whole surface of the counter without uncomfortable postures |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Pull-out work surfaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space on each side of the cooking surface |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the sink |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Pull-out work surfaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space on each side of the cooking surface |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the sink |
| Pull-out work surfaces | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space on each side of the cooking surface |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the sink |
| An appropriate counter space on each side of the cooking surface | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the sink |

### Factor 3- Operation of Controls with Perceptible Information

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Provision of helpful feedbacks by the refrigerator controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Provision of helpful feedbacks by the oven controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Provision of helpful feedbacks by the hood controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Provision of helpful feedbacks by the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the refrigerator about potential hazards |

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Provision of helpful feedbacks by the refrigerator controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the dishwasher about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability warning features of the cook-top about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on the counter |
| Provision of helpful feedbacks by the oven controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Provision of helpful feedbacks by the hood controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Provision of helpful feedbacks by the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the refrigerator about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the dishwasher about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability warning features of the cook-top about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on the counter |
| Provision of helpful feedbacks by the hood controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Provision of helpful feedbacks by the cook-top controls |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the refrigerator about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the dishwasher about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability warning features of the cook-top about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on the counter |
| Provision of helpful feedbacks by the cook-top controls | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the refrigerator about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the dishwasher about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability warning features of the cook-top about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on counter |

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Availability of warning features of the refrigerator about potential hazards | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability of warning features of the dishwasher about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability warning features of the cook-top about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on the counter |
| Availability of warning features of the dishwasher about potential hazards | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Availability warning features of the cook-top about potential hazards |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on the counter |
| Availability warning features of the cook-top about potential hazards | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Rounded edges on the counter |

## Factor 4- Adequate Illumination

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Adequate natural light in the kitchen | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate artificial light in the kitchen |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate illumination levels over the working surfaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate illumination levels above the cook-top |
| Adequate artificial light in the kitchen | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate illumination levels over the working surfaces |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate illumination levels above the cook-top |
| Adequate illumination levels over the working surfaces | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Adequate illumination levels above the cook-top |

### Factor 5- Ease of Reach to Oven

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ease of reach to all the essential elements of the oven from the positions where the person would like to be in | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | An appropriate counter space at least on one side of the oven |

| | **5** | **4** | **3** | **2** | **1** | **2** | **3** | **4** | **5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ease of reach to all the essential elements of the oven from the positions where the person would like to be in | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Close approach to the oven |
| An appropriate counter space at least on one side of the oven | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Close approach to the oven |

**Factor 6- Ease of Reach to Base Cabinets**

| | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ease of reach to the low portions of the base cabinets | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Ease of use of the rear portions of the base cabinets |
| | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Effective end efficient use of corner cabinets by 360° rotating mechanisms/lazy-susan units/moon swing-out shelves |
| Ease of use of the rear portions of the base cabinets | <<<< | <<< | << | < | = | > | >> | >>> | >>>> | Effective end efficient use of corner cabinets by 360° rotating mechanisms/lazy-susan units/moon swing-out shelves |

# APPENDIX G. The Pair-Wise Comparison Matrices and Priority Weights of the Six UKRs

## Appendix G.1 Matrices According to Value

**High Category** λ max=1.9941

| | Appropriate Counter Heights and Spaces | Operation of Controls with Perceptible Information | Weight |
|---|---|---|---|
| Appropriate Counter Heights and Spaces | 1.00 | 3.66 | 0.786 |
| Operation of Controls with Perceptible Information | 0.27 | 1.00 | 0.214 |

**Medium Category** λ max=1.9950

| | Adequate Illumination | Ease of Reach to Oven | Weight |
|---|---|---|---|
| Adequate Illumination | 1.00 | 3.00 | 0.750 |
| Ease of Reach to Oven | 0.36 | 1.00 | 0.250 |

**Low Category** λ max=2.0392

| | Operation of Controls with Less Force | Ease of Reach to Base Cabinets | Weight |
|---|---|---|---|
| Operation of Controls with Less Force | 1.00 | 0.36 | 0.257 |
| Ease of Reach to Base Cabinets | 3.00 | 1.00 | 0.743 |

# Appendix G.2 Matrices According to Cost

**High Category** λ max=2.0054

| | Appropriate Counter Heights and Spaces | Operation of Controls with Perceptible Information | Weight |
|---|---|---|---|
| Appropriate Counter Heights and Spaces | 1.00 | 0.38 | 0.275 |
| Operation of Controls with Perceptible Information | 2.66 | 1.00 | 0.725 |

**Medium Category** λ max=1.9950

| | Adequate Illumination | Ease of Reach to Oven | Weight |
|---|---|---|---|
| Adequate Illumination | 1.00 | 3.00 | 0.750 |
| Ease of Reach to Oven | 0.33 | 1.00 | 0.250 |

**Low Category** λ max=1.8155

| | Operation of Controls with Less Force | Ease of Reach to Base Cabinets | Weight |
|---|---|---|---|
| Operation of Controls with Less Force | 1.00 | 0.25 | 0.234 |
| Ease of Reach to Base Cabinets | 2.66 | 1.00 | 0.766 |

# APPENDIX H. The Pair-Wise Comparison Matrices and Priority Weights of all the Sub-UKRs

## H.1 Comparison Matrices According to Value

**Appropriate Counter Heights and Spaces (High)** λ max=7.5500

| | Q17 | Q19 | Q84 | Q18 | Q20 | Q22 | Q24 | Weight |
|---|---|---|---|---|---|---|---|---|
| **Q17** | 1.00 | 4.66 | 2.66 | 2.33 | 2.66 | 0.33 | 0.44 | **0.175** |
| **Q19** | 0.21 | 1.00 | 0.38 | 0.83 | 0.66 | 0.30 | 0.44 | **0.056** |
| **Q84** | 0.37 | 2.66 | 1.00 | 2.66 | 3.66 | 0.44 | 0.5 | **0.133** |
| **Q18** | 0.42 | 1.33 | 0.37 | 1.00 | 2.33 | 0.38 | 0.5 | **0.083** |
| **Q20** | 0.37 | 1.66 | 0.27 | 0.42 | 1.00 | 0.25 | 0.38 | **0.057** |
| **Q22** | 3.33 | 3.33 | 2.33 | 2.66 | 4.00 | 1.00 | 2.33 | **0.305** |
| **Q24** | 2.33 | 2.33 | 2.00 | 2.00 | 2.66 | 0.42 | 1.00 | **0.191** |

**Operation of Controls with Perceptible Information (High)** λ max=8.4422

| | Q56 | Q66 | Q76 | Q61 | Q28 | Q37 | Q31 | Q25 | Weight |
|---|---|---|---|---|---|---|---|---|---|
| **Q56** | 1.00 | 0.24 | 0.26 | 0.21 | 0.44 | 0.33 | 0.26 | 0.30 | **0.034** |
| **Q66** | 4.33 | 1.00 | 1.66 | 0.27 | 3.00 | 1.66 | 0.23 | 2.33 | **0.123** |
| **Q76** | 3.66 | 0.33 | 1.00 | 0.44 | 3.33 | 2.66 | 0.23 | 2.00 | **0.112** |
| **Q61** | 4.66 | 3.66 | 2.33 | 1.00 | 4.66 | 2.66 | 0.27 | 2.33 | **0.208** |
| **Q28** | 2.33 | 0.33 | 0.30 | 0.21 | 1.00 | 0.38 | 0.20 | 0.23 | **0.041** |
| **Q37** | 3.00 | 0.66 | 0.38 | 0.38 | 2.66 | 1.00 | 0.21 | 0.38 | **0.069** |
| **Q31** | 4.66 | 2.60 | 2.60 | 3.66 | 5.00 | 4.66 | 1.00 | 3.33 | **0.322** |
| **Q25** | 3.33 | 0.44 | 0.50 | 0.44 | 2.60 | 2.33 | 0.30 | 1.00 | **0.091** |

**Adequate Illumination (Medium)** λ max=4.2973

| | Q81 | Q82 | Q80 | Q79 | Weight |
|---|---|---|---|---|---|
| **Q81** | 1.00 | 0.30 | 2.66 | 3.00 | **0.258** |
| **Q82** | 3.33 | 1.00 | 3.66 | 2.33 | **0.493** |
| **Q80** | 0.38 | 0.27 | 1.00 | 1.66 | **0.130** |
| **Q79** | 0.36 | 0.44 | 0.66 | 1.00 | **0.119** |

**Ease of Reach to Oven (Medium)** λ max=3.2971

| | Q33 | Q23 | Q32 | Weight |
|---|---|---|---|---|
| **Q33** | 1.00 | 0.38 | 0.83 | **0.206** |
| **Q23** | 2.66 | 1.00 | 1.00 | **0.409** |
| **Q32** | 1.33 | 1.50 | 1.00 | **0.385** |

**Operation of Controls with Less Force (Low)** λ max=12.1793

| | Q45 | Q57 | Q55 | Q62 | Q44 | Q14 | Q60 | Q47 | Q51 | Q67 | Q65 | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q45** | 1.00 | 2.00 | 1.66 | 0.66 | 2.00 | 0.50 | 0.61 | 0.31 | 2.00 | 0.66 | 0.61 | **0.067** |
| **Q57** | 0.61 | 1.00 | 1.00 | 0.55 | 0.66 | 0.33 | 0.61 | 0.26 | 2.00 | 0.52 | 0.55 | **0.048** |
| **Q55** | 0.66 | 1.00 | 1.00 | 0.58 | 0.83 | 0.38 | 0.61 | 0.21 | 0.83 | 0.61 | 0.61 | **0.045** |
| **Q62** | 1.66 | 2.33 | 2.33 | 1.00 | 2.00 | 2.33 | 0.55 | 0.33 | 2.33 | 2.00 | 1.33 | **0.107** |
| **Q44** | 0.61 | 1.66 | 1.33 | 0.61 | 1.00 | 0.38 | 0.61 | 0.21 | 1.00 | 0.66 | 0.66 | **0.051** |
| **Q14** | 2.00 | 3.00 | 2.66 | 0.44 | 2.66 | 1.00 | 0.66 | 0.25 | 2.00 | 0.66 | 0.61 | **0.084** |
| **Q60** | 2.00 | 2.00 | 2.00 | 2.33 | 2.00 | 1.66 | 1.00 | 0.27 | 2.00 | 2.00 | 2.00 | **0.125** |
| **Q47** | 3.66 | 4.00 | 4.66 | 3.00 | 4.66 | 4.00 | 3.66 | 1.00 | 3.33 | 2.33 | 2.66 | **0.237** |
| **Q51** | 0.61 | 0.61 | 1.33 | 0.58 | 1.00 | 0.61 | 0.61 | 0.30 | 1.00 | 0.55 | 0.61 | **0.049** |
| **Q67** | 1.66 | 2.66 | 2.00 | 0.61 | 1.66 | 1.66 | 0.61 | 0.44 | 2.33 | 1.00 | 1.66 | **0.095** |
| **Q65** | 2.00 | 2.33 | 2.00 | 0.83 | 1.66 | 2.00 | 0.38 | 0.61 | 2.00 | 0.66 | 1.00 | **0.092** |

**Ease of Reach to Base Cabinets (Low)** λ max=3.1016

| | Q7 | Q9 | Q12 | Weight |
|---|---|---|---|---|
| **Q7** | 1.00 | 3.66 | 0.38 | **0.303** |
| **Q9** | 0.27 | 1.00 | 0.27 | **0.113** |
| **Q12** | 2.66 | 3.66 | 1.00 | **0.584** |

## H.2 Comparison Matrices According to Cost

**Appropriate Counter Heights and Spaces (High)** λ max=8.5472

| | Q17 | Q19 | Q84 | Q18 | Q20 | Q22 | Q24 | Weight |
|---|---|---|---|---|---|---|---|---|
| **Q17** | 1.00 | 0.21 | 0.26 | 0.50 | 0.26 | 2.00 | 2.00 | **0.079** |
| **Q19** | 4.66 | 1.00 | 0.33 | 0.33 | 0.44 | 0.33 | 0.33 | **0.088** |
| **Q84** | 4.66 | 3.33 | 1.00 | 0.50 | 0.50 | 2.33 | 2.33 | **0.176** |
| **Q18** | 2.00 | 3.33 | 2.00 | 1.00 | 3.33 | 3.33 | 3.33 | **0.275** |
| **Q20** | 4.66 | 2.33 | 2.00 | 0.33 | 1.00 | 3.33 | 3.33 | **0.210** |
| **Q22** | 0.50 | 3.33 | 0.44 | 0.33 | 0.33 | 1.00 | 1.00 | **0.087** |
| **Q24** | 0.50 | 3.33 | 0.44 | 0.30 | 0.30 | 1.00 | 1.00 | **0.085** |

**Operation of Controls with Perceptible Information (High)** λ max=9.8674

| | Q56 | Q66 | Q76 | Q61 | Q28 | Q37 | Q31 | Q25 | Weight |
|---|---|---|---|---|---|---|---|---|---|
| **Q56** | 1.00 | 0.33 | 0.50 | 0.33 | 0.33 | 0.33 | 3.33 | 4.66 | **0.089** |
| **Q66** | 3.33 | 1.00 | 2.00 | 0.44 | 2.00 | 2.00 | 3.33 | 4.66 | **0.182** |
| **Q76** | 2.00 | 0.50 | 1.00 | 0.50 | 3.33 | 3.33 | 3.33 | 4.66 | **0.169** |
| **Q61** | 3.33 | 2.33 | 2.00 | 1.00 | 3.33 | 3.66 | 2.00 | 4.66 | **0.235** |
| **Q28** | 3.33 | 0.50 | 0.33 | 0.33 | 1.00 | 0.33 | 0.26 | 4.66 | **0.078** |
| **Q37** | 3.33 | 0.50 | 0.33 | 0.27 | 3.33 | 1.00 | 0.33 | 4.66 | **0.103** |
| **Q31** | 0.33 | 0.33 | 0.33 | 0.50 | 4.66 | 3.33 | 1.00 | 4.66 | **0.121** |
| **Q25** | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 1.00 | **0.023** |

**Adequate Illumination (Medium)** λ max=4.3378

| | Q81 | Q82 | Q80 | Q79 | Weight |
|---|---|---|---|---|---|
| **Q81** | 1.00 | 3.33 | 3.33 | 4.66 | **0.515** |
| **Q82** | 0.33 | 1.00 | 0.33 | 3.33 | **0.146** |
| **Q80** | 0.33 | 3.33 | 1.00 | 3.66 | **0.271** |
| **Q79** | 0.21 | 0.33 | 0.27 | 1.00 | **0.068** |

**Ease of Reach to Oven (Medium)** λ max=3.1533

| | Q33 | Q23 | Q32 | Weight |
|---|---|---|---|---|
| **Q33** | 1.00 | 3.33 | 2.33 | **0.551** |
| **Q23** | 0.33 | 1.00 | 0.33 | **0.132** |
| **Q32** | 0.44 | 3.33 | 1.00 | **0.317** |

**Operation of Controls with Less Force (Low)** λ max=12.3200

| | Q45 | Q57 | Q55 | Q62 | Q44 | Q14 | Q60 | Q47 | Q51 | Q67 | Q65 | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Q45** | 1.00 | 3.33 | 3.33 | 0.50 | 1.00 | 2.33 | 0.44 | 0.44 | 2.00 | 0.50 | 0.50 | **0.087** |
| **Q57** | 0.33 | 1.00 | 1.66 | 0.66 | 1.00 | 0.33 | 0.44 | 0.44 | 2.00 | 0.50 | 0.33 | **0.049** |
| **Q55** | 0.33 | 0.66 | 1.00 | 0.50 | 1.00 | 0.33 | 0.50 | 0.50 | 1.00 | 0.50 | 0.33 | **0.042** |
| **Q62** | 2.33 | 2.66 | 2.33 | 1.00 | 2.00 | 0.38 | 1.00 | 0.33 | 3.66 | 1.00 | 1.66 | **0.106** |
| **Q44** | 1.00 | 1.00 | 1.00 | 0.50 | 1.00 | 0.38 | 0.50 | 0.33 | 2.00 | 0.50 | 0.50 | **0.047** |
| **Q14** | 0.44 | 3.33 | 3.33 | 2.66 | 2.66 | 1.00 | 2.00 | 0.33 | 2.33 | 0.44 | 0.44 | **0.106** |
| **Q60** | 2.33 | 2.33 | 2.00 | 1.00 | 2.00 | 0.50 | 1.00 | 0.37 | 1.00 | 0.50 | 1.00 | **0.084** |
| **Q47** | 2.33 | 2.33 | 2.00 | 3.33 | 3.33 | 3.33 | 2.66 | 1.00 | 1.66 | 2.00 | 2.66 | **0.199** |
| **Q51** | 0.50 | 0.50 | 1.00 | 0.27 | 0.50 | 0.44 | 1.00 | 0.66 | 1.00 | 0.38 | 0.33 | **0.044** |
| **Q67** | 2.00 | 2.00 | 2.00 | 1.00 | 2.00 | 2.33 | 2.00 | 0.50 | 2.66 | 1.00 | 1.66 | **0.122** |
| **Q65** | 2.00 | 3.33 | 3.33 | 0.66 | 2.00 | 2.33 | 1.00 | 0.38 | 3.33 | 0.66 | 1.00 | **0.114** |

**Ease of Reach to Base Cabinets (Low)** λ max=3.0427

| | Q7 | Q9 | Q12 | Weight |
|---|---|---|---|---|
| **Q7** | 1.00 | 0.33 | 0.21 | **0.115** |
| **Q9** | 3.33 | 1.00 | 1.00 | **0.417** |
| **Q12** | 4.66 | 1.00 | 1.00 | **0.468** |

## APPENDIX I. Software Acceptance Questionnaire (SAQ)

The Software Acceptance Questionnaire (SAQ) is intended to assess the user acceptance of the Computer-Assisted Universal Design (CAUD) plug-in tool. The questionnaire consists of three parts. Following closed ended questions about the usefulness, clarity, efficiency, support/help and satisfaction, open ended questions are directed to identify the favourite functions of the plug-in tool, its missing characteristics and any problems faced during usage. In order to gather demographic information about participants, background questions are asked in the last part of the questionnaire. The results of the questionnaire will be used only for academic purposes. We thank you for your help and cooperation.

**Part 1**

For each of the following statements, please circle one of the points on the scale to indicate how much you agree or disagree with it.

| **Usefulness** | Strongly Agree | | | | | | Strongly Disagree |
|---|---|---|---|---|---|---|---|
| 1. The plug-in tool will be very useful to me. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 2. I do not see any advantage in using the plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 3. I can see a lot of possible ways of making use of this plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 4. I would prefer to achieve the same task without the plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 5. The plug-in tool does not really do what I want. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

| **Clarity** | Strongly Agree | | | | | | Strongly Disagree |
|---|---|---|---|---|---|---|---|
| 6. The layout of the information is clear. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 7. The instructions and messages are understandable. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 8. It is not always obvious what to do next. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 9. The plug-in tool seems to work in a logical way. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 10. The displays are very cluttered. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

| Efficiency | Strongly Agree | | | | | | Strongly Disagree |
|---|---|---|---|---|---|---|---|
| 11. I feel I can achieve tasks quickly with the plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 12. I cannot easily find the part of the plug-in tool I want. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

| Efficiency | Strongly Agree | | | | | | Strongly Disagree |
|---|---|---|---|---|---|---|---|
| 13. I feel in control of the plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 14. I am able to move around the plug-in tool as I wish. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 15. I have to go through a lot of irrelevant stages to get to the result I want. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

| Support/Help | Strongly Agree | | | | | | Strongly Disagree |
|---|---|---|---|---|---|---|---|
| 16. The plug-in tool is good at indicating what to do next. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 17. The plug-in tool does not seem to help me in the way that I need. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 18. The plug-in tool often leaves me unsure how to continue. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 19. I have to ask others if I get into difficulties. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 20. I feel confident of overcoming any problems I have with the plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

| Satisfaction | Strongly Agree | | | | | | Strongly Disagree |
|---|---|---|---|---|---|---|---|
| 21. The plug-in tool is interesting to use. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 22. I often get frustrated when using the plug-in tool. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 23. I would like to learn more about the system. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 24. Using the plug-in tool gives me a sense of achievement. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| 25. Working with the plug-in tool is enjoyable. | 7 | 6 | 5 | 4 | 3 | 2 | 1 |

**Part 2**

26. Do you have a favourite plug-in tool function? If yes, please explain.
27. Is there anything that you miss in the plug-in tool? If yes, please explain.
28. Did you have any problem with the plug-in tool? If yes, please explain.
29. Can you give an explanation for the questions that you answered with either a 1 or a 7?
30. Do you have any further remarks and/or suggestions about the plug-in tool?

**Part 3- Background questions**

I am a:

- ☐ Man
- ☐ Woman

My age is: ………………………………………………………………

The level of my experience with the SkecthUp software is:

- ☐ Below 1 years
- ☐ 1-3 years
- ☐ Above 3 years
- ☐ Others, like ………………………………………………………

My activities in this field are……………………………………………

The level of my English is:

- ☐ Poor
- ☐ Moderate
- ☐ Good
- ☐ Native speaker

My nationality is ………………………………………………….........

I come from …………………………………………………………........

My profession is ……………………………………………………......