2011

A Model To Integrate Sustainability Into The User-centered Design Process

Adrienne Shevonne Brown
University of Central Florida

A MODEL TO INTEGRATE SUSTAINABILITY INTO THE USER-CENTERED DESIGN PROCESS

by

ADRIENNE SHEVONNE BROWN
B.S. Florida Agricultural and Mechanical University, 2004

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Fall Term
2011

ABSTRACT

With concerns for the environment becoming more prevalent in business and the government, it is increasingly important to re-evaluate and update processes to include sustainability considerations early in the design process. In response to this charge, this research effort was designed to integrate sustainability factors into the user-centered design process. The results of this research highlight the benefits of sustainability requirement planning, as well as those derived from integrating sustainability into the current user-centered design model.

I dedicate this work to my family, friends, and future generations. To my parents, Mr. Waymon Brown III and Ms. Gina Powell, I thank you for always supporting me, no matter what. Thank you for being my sounding boards, guiding forces, voices of reason, and constant motivators. To my grandparents, Mr. Waymon Jr. and Mrs. J. Synovia Brown thank you for instilling in me the importance of education and always pushing me to achieve my dreams. Thank you for teaching me to be a "global citizen" before it was the “in” thing to do. To future generations, be encouraged to work towards the world you want to see.

ACKNOWLEDGMENTS

Special thanks to Dr. Crumpton-Young, Dr. McCauley-Bush, and Dr. Nazzal for supporting me in completing this work. You have been great teachers, mentors, and resources during my graduate education at UCF and I appreciate your influence on me. I also want to thank my family and friends for supporting me when I needed it and gave me boosts of encouragement to complete this document.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

This research will provide a model influenced by user-centered design, with modification to the recognized user-centered design process to account for current trends in design, in particular the integration of sustainability. User-centered design (UCD) is defined, “an approach to design that grounds the process in information about the people who will use the product” (Usability Professionals' Association, 2011).

In addition to user-centered design, many global organizations have made investments in sustainability. Sustainable development, also known as sustainability, as defined by the World Commission on Environment and Development’s *Our Common Future,* is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). Greenwood (2011) puts the definition in simpler terms, stating, "sustainability is the ability of a system to be sustained [indefinitely]". He also states that sustainable design is "the design of systems that can be sustained [indefinitely]" and sustainable product design as "the design of objects that aid the sustainability of the systems in which they operate" (Greenwood, 2011). Taking into account the definitions of user-centered design and sustainability, this model seeks to address sustainability, in particular as it applies to user-centered design.

The vision of this research is to create a hybrid model of user-centered design by incorporating sustainability components. Sustainability covers a variety of topics including the environment, energy, agriculture, and water, to name a few. By implementing the hybrid model created in this research, the desired effect is to influence engineers and designers to produce sustainable products and systems, from a user-centered design standpoint.

The challenge that this research seeks to address is the manufacture of goods designed with sustainability in mind. By addressing sustainability in the analysis phase of the process, a product or system that reflects the core aim of “designing for the environment” will become the norm and not the exception. The implementation of the hybrid model of user-centered design will lead to a shift in mindset; achieved by eliminating a post-manufacture test to determine if consideration for sustainability occurred, because the process will encompass sustainability from the initial concept of the design.

Additionally, the intent is that in developing new designs, products, and systems to reflect the core of what sustainability conveys, the technology used to create said designs, products, and systems, will reflect sustainability. An option for achieving this goal is to implement green technologies, such as renewable energy and environmental construction, into the manufacturing process. Environmental construction is an initiative led by the U.S. Green Building Council (USGBC). As stated on their website, the USGBC is a "non-profit community of leaders working to make green buildings available to everyone within a generation" (U.S. Green Building Council, 2011).

The proposed research will fill a gap on the national and international levels. By defining a model that sets out to be sustainably responsible, its adoption by organizations will lead to the fulfillment of sustainable user-centered design. The target is for the hybrid model to be widely accepted, as is the current user-centered design model. This research will strive to meet the needs of many national and international organizations. The following organizations currently incorporate sustainability into their business goals:

1. Apple – An electronics producer of computers, laptops, MP3 players and other items considers the impact of their products, particularly what happens when they are designed, what happens when they are manufactured, and what happens when they bought and used by the consumer (Apple, Inc., 2011).
2. IDEO – "An award-winning global design firm that takes a human-centered, design-based approach to helping organizations in the public and private sectors innovate and grow" (IDEO, Inc., 2011). IDEO is also responsible for developing the Human-Centered Design Toolkit, "an open-source toolkit to inspire new solutions in the developing world" (IDEO, Inc., 2011).

3. Boeing – Boeing is “the world's largest aerospace company and leading manufacturer of commercial jetliners and defense, space and security systems" (Boeing, 2011). Boeing recently introduced the 787 Dreamliner, an aircraft that "incorporates advanced composite materials, systems and engines to provide unprecedented performance levels, including a 20 percent improvement in fuel efficiency over existing small twin-aisle airplanes" (Boeing, 2011). The Dreamliner and other product initiatives incorporate more sustainable technologies.
4. Arup – Arup is "an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services" (Arup, 2011). Arup offers sustainability consulting, "comprehensive services aimed at developing and implementing policies, plans, strategies and management systems, assessing impacts, managing risk, designing mitigation measures, gaining regulatory approvals, undertaking audits and reviews, reporting publicly and controlling costs" (Arup, 2011). As part of the sustainability consulting services, Arup developed SPeAR® (Sustainable Project Appraisal Routine), "an integrated decision-making tool used to support project development" and "assist with improving the social, economical, and environmental performance of projects" (Arup, 2011).

The U.S. is a developed country with extensive manufacturing ventures, providing the opportunity to alter how to conduct business, by ensuring to adopt a culture of sustainability. Much like the way that many large organizations implement Lean Six Sigma, the objective of the hybrid user-centered design model is to improve business systems. The key is to find the balance between the three main pillars of sustainability: social, environmental, and economical.

Adoption of the hybrid model will influence organizations in the U.S. and other countries to address sustainability in their user-centered design processes. Developing countries who implement the hybrid model that focuses on sustainability can make strides towards equality in the area of product and system developments with developed countries. One way to achieve this goal is introducing the hybrid model into the educational system; the target is the hybrid model will influence students to think proactively about sustainability and implement it into their design concepts.

One of the specific aims of this research is to create a shift in focus of user-centered design. Although the goal is not to replace users as the focus of the design process, the objective is to elevate the importance of sustainability to the same level as user focus. Specific areas to address with the aim of reaching the goals of this research are to define the hybrid model, create a visual, and show the benefits. By defining the hybrid model, persons in industry will be able to determine if it is applicable to their organization and apply it to their processes. Having a visual of the hybrid model allows individuals to see the similarities and differences to the traditional user-centered design process. By applying this research to already existing products or systems, evaluation of the hybrid model can assess if it has an added benefit to the original design process.

The outcomes of this research include creation of a hybrid model that integrates multiple components of traditional user-centered design processes used by various organizations, with the main areas of sustainability. In addition to the hybrid model, another outcome will be an evaluation tool to measure the level of sustainability that a product possesses.

CHAPTER 2: LITERATURE REVIEW

This chapter provides background information on user-centered design and sustainability, such as definitions, historical background, methodology used for user-centered design and benefits achieved through implementing user-centered design into product and/or system design. Additionally, this chapter includes observation of the gaps that exist between user-centered design and sustainability, and how this research effort addresses these gaps.

2.1 User-Centered Design

User-centered design (UCD) is a term used to describe the design process in which the user is the central focus. The aim of this philosophy is to create a product that focuses on what the user really wants. According to Abras et al (Abras, Maloney-Krichmar, & Preece, 2004), “the term 'user-centered design' originated in Donald Norman's research laboratory at the University of California San Diego (UCSD) in the 1980s and became widely used after the publication of a co-authored book entitled: *User Centered System Design: New Perspectives on Human-Computer Interaction”* (Norman & Draper, 1986). This book focuses on the designs of computers and how the user should be the center consideration from which the design springs.

In Norman's *The Psychology of Everyday Things*, he suggests that there are four things driving the intent of designing for users:

- Make it easy to determine what actions are possible at any moment.
- Make things visible, including the conceptual model of the system, the alternative actions, and results of the actions.
- Make it easy to evaluate the current state of the system.
- Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state (Norman, 1988).

Meza (2008) states that, "the usability of the product and the user experience must be included in the design requirements" for successful user-centered design. Usability is defined by the following characteristics: efficiency, effectiveness, safety, must have good utility, and must be easy to remember and learn (Meza, 2008). Additionally, the user experience goals are "product being satisfying, fun, emotionally, fulfilling, rewarding, supportive of creativity, aesthetically pleasing, motivating, helpful, entertaining, enjoyable" (Meza, 2008).

The application of user-centered design in different industries leads to a model that best fits the requirements of the business; many times, this leads to customization of the process. The National Aeronautic and Space Administration (NASA) implement a five-stage process to develop user-centered web sites, as seen in Table 1.

Table 1: NASA 5 Stages of UCD Process (National Aeronautics and Space Administration, 2011)

REQUIREMENTS AND PLANNING: Getting Started		
Tasks and Activities	Deliverables	Usability Test Methods
• site strategy • user needs assessment	• project plan (that includes usability testing) • schedule • build project team • set high level site goals	• personal interview • contextual inquiry • surveys • focus groups
CONCEPTUAL DESIGN: Creating the Framework and Flow		
Tasks and Activities	Deliverables	Usability Test Methods
• task design • information architecture • audit existing content • outline new content • usability testing	• develop site map • define navigation framework • set naming conventions • storyboards • content delivery plan	• exploratory tests • task flow storyboards • card sort/reverse card sort
DETAILED DESIGN: Designing the Look and Feel		
Task and Activities	Deliverables	Usability Test Methods
• review site goals • presentation design • content design • interaction design • 508 accessibility compliance assessment • usability testing	• paper prototypes • wireframes • high fidelity mock-ups • functioning prototypes • write style guide • design graphical templates • usability test plan and recommendations • launch and implementation plan	• user performance tests on mock-ups and prototypes • task modeling assessment • usability questionnaires • review templates against style guide
PRODUCTION: Building the Site		
Task and Activities	Deliverables	Usability Test Methods
• review and follow style guide • build HTML templates • populate pages • integrate with back end • final 508 accessibility compliance assessment • final usability testing • launch site	• usability test plan and recommendations • optimized graphics	• user performance tests on functioning development site
MAINTENANCE: Monitoring and Updating		
Task and Activities	Deliverables	Usability Test Methods
• launch site • monitor user feedback • monitor web stats • usability test new features and changes prior to launch	• maintenance plan • assign maintenance team	• user comments • user surveys • server logs • expert review • user performance tests on live site • user performance tests on new feature prototypes

Another model that focuses on product design, instead of web site design, is that of Kankainen (2003). Kankainen's objective is to create a process that focuses on user-centered product concept design (UCPCD). The UCPCD process is shown in Figure 1.

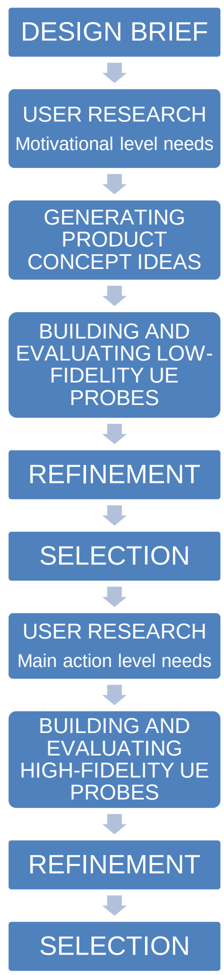

Figure 1: UCPCD Process (Kankainen, 2003)

Kankainen's process studies the motivational-level needs, as well as action-level needs, with a commonality of the two being narratives; narratives are used through the whole process. "Narratives can be used in all activities of user-centered product concept design, from user research that, in this view, is for collecting user narratives, and ending with UE [user experience] probe evaluation that provides narratives on how users could use the product concepts in the future" (Kankainen, 2003).

Meza's (2008) model is different in comparison to Kankainen's model, but it too grasps the essence of user-centered design. Meza characterized user-centered design into components and subcomponents to illustrate the relationships for her taxonomy built to measure the impact of user-centered design. Table 2 outlines the components and sub-components of the taxonomy application.

Table 2: User-centered design components and sub-components (Meza, 2008)

User - Centered Design Components	
Component	***Sub-components***
Physical Design	• Anthropometry • Muscular Activity • Body Position • Body Posture • Repetitive Motion • Strength Needed
Industrial Design	• Illumination/Lighting • Function • Vibration • Sound/Noise • Temperature • Form
Cognitive Design	• Memorability • Ease of use • Usability
User Experience Design	• Desirable • Valuable • Usable • Findable • Credible • Accessible • Useful

With differing ways to implement user-centered design, it may be hard to determine the potential benefits of incorporating user-centered design into product or system design. Kuniavsky shares that the user experience is a long-term commitment, "a solution that makes immediate financial and corporate sense" (2003). By focusing on the user, businesses develop a product or system that customers want, thus increasing their profits. Additional reasons for including user-centered design into the overall development process include:

1. Efficiency - use of resources, clear road map before launch, reduced support after launch
2. Reputation - user satisfaction leads to continued use of product and sharing with others
3. Competitive advantage - ability to identify gaps in user needs of competition, which leads to innovation drive (proactive)
4. Trust - product delivers on what it says it will, user is loyal, satisfied, and patient
5. Profit - lower costs without sacrificing quality leads to more customers and better value to stakeholders (Kuniavsky, 2003).

To support the claims of Kuniavsky, Abras et al state that advantages of including consideration for user-centered design are "a deeper understanding of the psychological, organizational, social and ergonomics factors" that affect users, which in turn leads to "the development of products that are more effective, efficient, and safe" (Abras, Maloney-Krichmar, & Preece, 2004).

There are many different approaches used to assess the degree to which a product adheres to user-centered design specifications. Many designers choose to use product or system evaluation tools to gauge how user-centered design criteria are met. Van Velsen et al. (2008) state that user-centered evaluation (UCE) serves three goals, including: "verifying quality of a product, detecting problems and supporting decisions. They also defined UCE as the following

> "an empirical evaluation obtained by assessing user performance and user attitudes towards a system, by gathering subjective user feedback on effectiveness and satisfaction, quality of work, support and training costs or user health and well-being" (Van Velsen, Van der Geest, Klaasen, & Steehouder, 2008).

Meza (2008) used evaluations based on Cognitive, Industrial, Physical, and User Experience design to determine how a product met user-centered design goals. IBM® uses a UCD Progress Report, where goals and progress are charted to determine the status of a project (IBM® Design: UCD Process, 2011). Figure 2 shows what the UCD report looks like; some of the information captured is project leader, schedule, budget, and user problems, among others.

UCD Report

Project Information

UCD Project Leader	User Audience	Prime Competitor	Fixed Rate Model
?	?	?	?

User Problem Summary

Severity	Number	% Fixed	Target
1	?	?%	?%
2	?	?%	?%
3	?	?%	?%

Ease of Use Objectives

Objective	Validation	Status
?	?	?
?	?	?
?	?	?

Top 5 Open User Problems

Priority	Severity	Problem Description	Data Identified	Fix Date
1	?	?	?	?
2	?	?	?	?
3	?	?	?	?
4	?	?	?	?
5	?	?	?	?

User Satisfaction

Baseline	Current	Target	Competition
?	?	?	?

Enablement

Team	Schedule	Training	Budget
?	?	?	?

User Involvement (hours)

Understand	Evaluate	Test	Total
?	?	?	?

Figure 2: IBM® UCD Report (IBM® Design: UCD Process, 2011)

Additional methods of validating the application of the user-centered design process for the creation of a product are by surveys and checklists. Often, the surveys and checklists highlight the major principles of user-centered design and observe measures based on a scale, much like an evaluation.

2.2 Sustainability

Merriam-Webster defines sustainability as "capable of being sustained; of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged" (Merriam-Webster, 2011). The Environmental Protection Agency (EPA) states sustainability is a simple principle: "everything that we need for survival and well-being depends, either directly or indirectly, on the natural environment" (Environmental Protection Agency, 2011). In essence, sustainability seeks to address the use of resources currently available without compromising the ability to utilize the same resources in the future. Additionally, sustainability addresses the ability to recycle and/or reclaim materials. Three main factors generally characterize the focus of sustainability: economics, environment and social.

Sustainability in design is a recent concept, emerging in the last couple of decades. Pushes for environmental awareness, such as the Clean Air Act, signed by then President Richard Nixon, increased the public's awareness of environmental issues. The United Nations has also been instrumental in the increase of awareness of environmental preservation over the course of recent decades. The United Nations Conference on the Human Environment (better known as the Stockholm Conference), was held in Stockholm, Sweden in 1972 (Environmental Protection Agency, 2011). At this conference, the term "sustainable development" was first introduced. From the Stockholm conference, was born the United Nations Environment Programme (UNEP).

The mandate of UNEP is "to promote the idea of environmentally-sound development" (Environmental Protection Agency, 2011).

The most noted introduction of the concept of sustainability was in 1987 at the United Nations conference, World Commission on Environment and Development (WCED), also known as the "Brundtland Commission". In the *Report of the World Commission on Environment and Development: Our Common Future* sustainable development, or sustainability, is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987).

According to the EPA, many other conferences and initiatives began in order to discuss environmental, sustainability, and development issues. A notable conference is the UN Conference on Environment and Development (UNCED) and Rio Earth Summit (1992), which in turn led to Agenda 21, President's Council on Sustainable Development (PCSD) (1993), Kyoto Climate Change Agreement (1997), and the World Summit on Sustainable Development (WSSD) (2001) (Environmental Protection Agency, 2011). These major events led to an increase of considering sustainability in many different areas, including, but not limited to architecture, business, agriculture, and engineering.

Architecture often exhibits sustainability in its efforts to promote green building, spearheaded by organizations such as the U.S. Green Building Council. Additionally, sustainability in business is becoming increasingly important, even spurring the creation of MBA programs with a sustainability focus. Closely tied to environmental sustainability is the field of agricultural. Frequently the focus of agricultural sustainability is the ecosystem and how chemicals. Engineering disciplines are now seeking to understand how sustainability can be included and implemented to better execute objectives.

Pereira states that sustainability in engineering requires "a holistic approach that uses an integral engineering method to provide for the primary needs of the population - shelter, water, food, energy and education" (Pereira, 2009). Although sustainability came to the forefront of concerns for international leaders in 1987, Pereira's concept for sustainability in engineering and sustainability in design are relatively new concepts. Architect William McDonough asserts the following, that "designing for sustainability requires awareness of the full short and long-term consequences of any transformation of the environment; sustainable design is the conception and realization of environmentally sensitive and responsible expression as a part of the evolving matrix of nature" (William McDonough Architects, 1992). Achieving sustainability is a short and long-term goal across different design fields, such as building design, urban design, and interaction design.

The initiative of the U.S. Green Building Council is one of the most well known instances of sustainability in design, introducing LEED, or Leadership in Energy and Environmental Design. LEED is an "internationally-recognized green building certification system" (U.S. Green Building Council, 2011). This program provides the tools for builders in the process of "green construction" and most notably provides a rating scale based on the aspects of the building that are based on sustainable design.

Another design initiative that seeks to incorporate sustainability into the process is that of urban design. Planners are often met with the challenge of integrating the three main factors of sustainability (economics, environment, and social) into a community design. Porta and Renne state that, "the concept of sustainability is only useful if we can gauge the impact of development upon the economy, the environment, and the wellness of the community" (Porta & Renne, 2005). The result was a development of an urban design tool that enables a "bridge between urban design and sustainability", using "Sustainable Development Indicators (SDI) to evaluate the environment (Porta & Renne, 2005).

Many models have been developed to incorporate sustainability into design processes. One such model is that of Sustainable Interaction Design (SID) introduced by Blevis. Blevis proposes that sustainability be the central focus of interaction design. Key items to consider in the model are "disposal, salvage, recycling, remanufacturing for reuse,

reuse as is, achieving longevity of use, sharing for maximal use, achieving heirloom status, finding wholesome alternatives to use, and active repair of misuse" (Blevis, 2007). "A goal of SID is to suggest ways in which sustainability concerns can be integrated into existing design methods or new design methods in a manner that yields sustainable interaction design as a practice" (Blevis, 2007).

Another area of design where sustainability is considered for integration is product design. Bras (1997) suggests that there are "several motivating factors for a company or organization to become more environmentally responsible". The factors that are "most notable" are legislation, customer demand, eco-labeling programs, and ISO 14000 (Bras, 1997). The goal of environmentally conscious design is the development of new tools to gauge the process. Bras (1997) states that such a tool to gauge the process should have seven characteristics. The characteristics are:

- Simple - they should be easy to use
- Easily Obtainable - at a reasonable cost
- Precisely Definable - it is clear as to how they can be evaluated
- Objective - two or more qualified observers should arrive at the same result
- Valid - they should measure, indicate, or predict *correctly* what they are intended to measure, indicate, or predict
- Robust - relatively insensitive to changes in the domain application, and

- Enhancement of Understanding and Prediction - good metrics, models and decision support tools should foster insight and assist in predicting process and product parameters (Bras, 1997).

Important to note is that although the development of tools is important in making the change in design towards sustainability, but also "perhaps the most important issue in moving towards integrating environmental issues in product design is education" (Bras, 1997).

Another concept to consider is the proposed methodology to evaluate product sustainability in the design and development stage of products introduced by Silva et al. Many products are disposed by two options: landfill or incineration. The method proposed, "provides a simplified product sustainability scoring technique where the inputs of the model consist of data available at a design stage of product development" (de Silva, Jawahir, Dillon Jr., & Russell, 2009). The model has acknowledged six "Sustainability Elements": product's environmental impact, societal impact, functionality, resource utilization and economy, manufacturability and recyclability/remanufacturability (de Silva, Jawahir, Dillon Jr., & Russell, 2009). Figure 3 shows six major "Sustainability Elements" of the Product Sustainability Scoring Model.

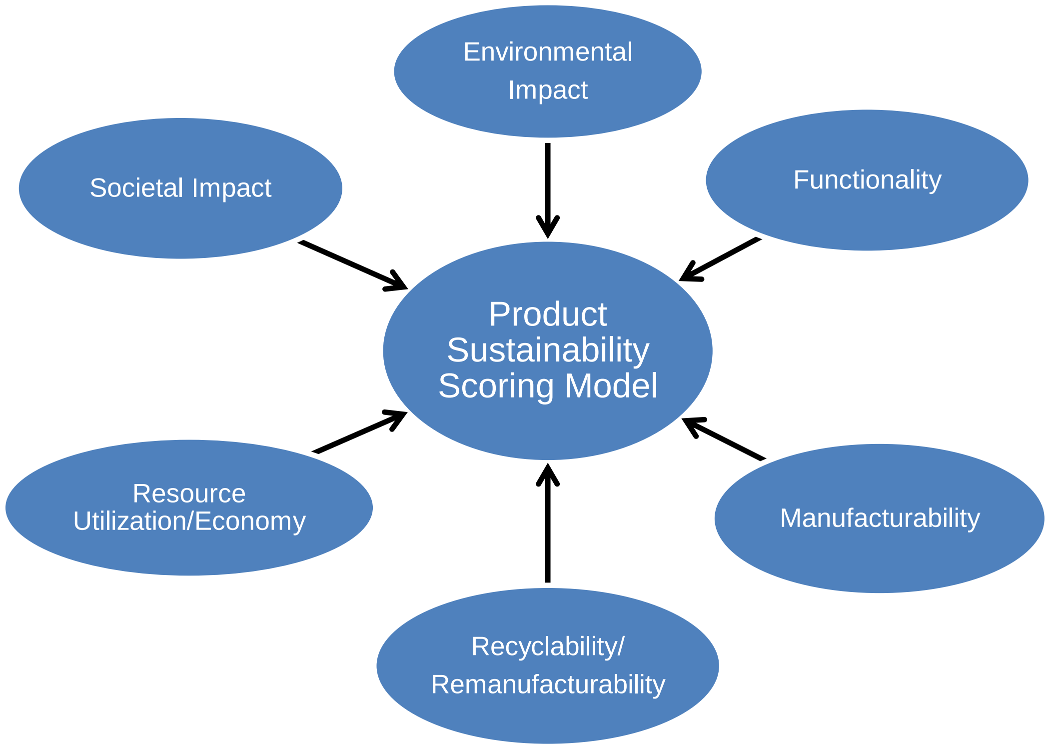

Figure 3: Six Major Sustainability Elements (de Silva, Jawahir, Dillon Jr., & Russell, 2009)

The elements of the model are then inserted into the framework suggested by Silva et al. which includes "44 influencing factors, 24 sub-elements, 6 sustainability elements, and product sustainability index", as shown in Figure 4.

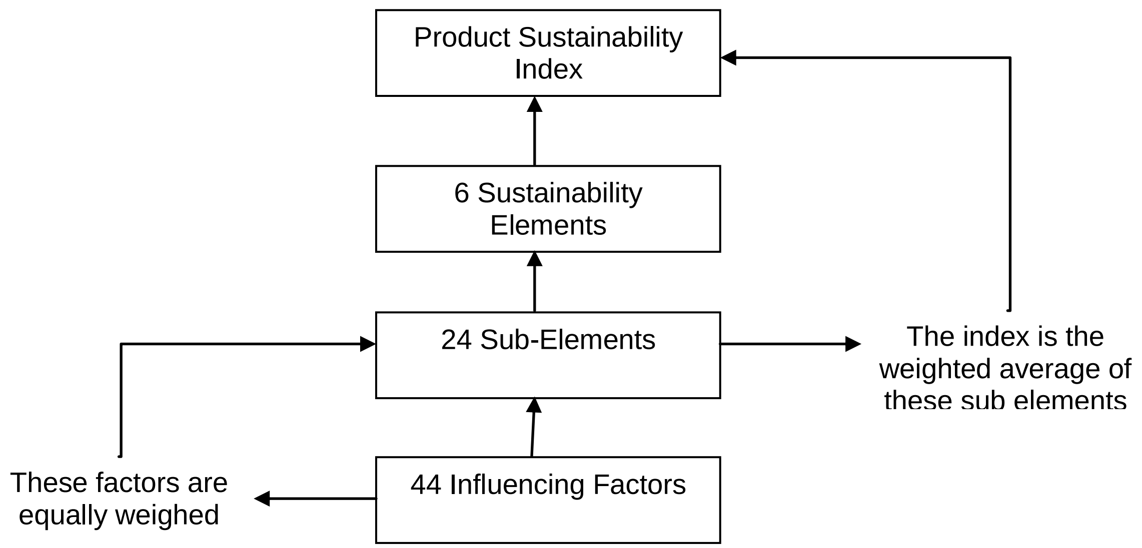

Figure 4: A New Framework for Product Sustainability Model (de Silva, Jawahir, Dillon Jr., & Russell, 2009)

A concluding remark from the team that developed this new methodology is it is a "simple model which is useful in decision making at the design stage of product development" (de Silva, Jawahir, Dillon Jr., & Russell, 2009).

Rouse (1991) describes the prerequisites of successful human-centered design as:

1. Long-term Perspective - planning for viability, acceptability, and validity measurements, for which closure will not be reached for several years
2. Sense of Accountability - both ethical and legal accountability are needed throughout design life cycle; motivates designers, as well as managers, to assure that they are meeting the needs of users, customers, and other stakeholders.

3. Flexible Design Process - that enables feedback of measurements into design refinements prior to production.
4. Cooperative User-Producer Relationships - the naturalist and marketing phases afford opportunities for building relationships, and the sales and service phase supplies the means for maintaining them (Rouse, 1991).

By incorporating sustainability into Rouse's prerequisites for successful human-centered design, the benefits are quite evident. When taking into consideration the economic benefits of sustainability, the launch of the Dow Jones Sustainability Index (DJSI) is a marker that sustainability is good business. Economics play an important role in sustainable development and it is important to explore "from an economic perspective a sustainable development path that maximizes the long-term net benefits to humankind, taking into account the costs of environmental and natural resource degradation" (Asefa, 2005). Thus, the economics of sustainability address, at least, the first two prerequisites of Rouse for successful design.

2.2.1 Three Factors of Sustainability

Three factors characterize sustainability: environmental, economical, and social. Environmental sustainability is probably the most popular and easily understood of the three factors of sustainability. The overall goal of environmental sustainability is to preserve resources provided by the environment for future generations and not to produce waste that destroys the current environment. That goal is synonymous with a term that is familiar with environment sustainability: "design for environment". Two goals of design for the environment, also known as DfE, are waste prevention and materials management (Bishop, 2000). Bishop (2000) also asserts other categories, which he calls "Design for X"; additional categories are shown in Table 3.

Table 3: Design for X Categories (Bishop, 2000)

Category	Acronym	Description
Environment	DfE	Implement pollution prevention, energy efficiency, and other resource conservation measures to reduce adverse impacts on human health and the environment
Manufacturability	DfM	Integrate a product's manufacturing requirements into fabrication and assembly processes available in the factory
Disassembly	DfA	Design the product for ease of disassembly and component/material reuse/recycling after the product's useful life is over
Recycle	DfR	Design the product so that it can be easily recycled
Serviceability	DfS	Design the product so that it can be easily installed, serviced, or repaired
Compliance	DfC	Design the product so that it meets all regulatory requirements

The aspect of sustainability that is of highest interest, especially to companies worried about profit, is economics. Economic sustainability is closely related to environmental for various reasons. One reason is liability associated with air pollution, water contamination, and health problems (Kutz, 2007). Another reason is the poverty level found in developing countries. Many impoverished persons in developing countries utilize the agriculture around them for sustenance and often participate in "slash-and-burn" techniques.

In addition to liability for government regulations and poverty in developing countries, other aspects that influence economic sustainability are product life cycle and product innovation. By taking into account the life cycle of a product, organizations can factor costs and savings in "product, waste treatment, and disposal" (Kutz, 2007). Leading in those areas may also lead to admission to the Dow Jones Sustainability Index, a confirming sign of the organization's commitment to sustainability. Product innovation lends itself to economics because the development of environmentally conscious products meets the current trend and demand, therefore increasing profit for an organization.

The social aspect is often the least defined regarded of sustainability. Environment and economics often take the forefront of one's understanding of the overall aspect of sustainability, while social sustainability is loosely defined. Magis and Shinn (2009) shared the belief that social sustainability is based on four principles: human well-being, equity, democratic government, and democratic civil society. Kutz (2007) shared similar views, stating that the social aspect of sustainability has a goal to ensure "health, well being, security, and a high quality of life". Based on the knowledge shared by Magis and Shinn and Kutz about social sustainability, it is evident human well-being and equity are two key factors; these are also key in user-centered design, always ensuring the well-being of the users and that the product exhibits reasonable accommodations for the intended population for which it was designed.

Another viewpoint of how social sustainability defined is from Hawkins (2006), who suggests that the basis of sustainability has many more factors:

- Culture - balance cultural diversity, while improving community well-being; globalization
- Age - Western culture is an aging community, despite expected population growth expected to exceed 7 billion in 20 years
- Urbanization - brought on by economic and political instability
- Religion - predominant religions of the world will be Christianity and Islam in next 20 years
- Education - increased numbers in large developing countries (India, China, Indonesia)
- Health - the spread of diseases such as HIV/AIDS and SARS
- Technology - digital communication and social media have bridge the global gap (Hawkins, 2006).

Kutz (2007) explores the three aspects of sustainability and the indicators of each. Table 4 shows the three factors of sustainability and some indicators that characterize each factor.

Table 4: Economic, Environmental, and Societal Performance Indicators for Sustainability Assessment (Kutz, 2007)

Economic	Environmental	Societal
Direct • Raw material Cost • Labor Cost • Capital Cost	Material Consumption • Product & packaging mass • Useful product lifetime • Hazardous materials used	Quality of Life • Breadth of product availability • Knowledge or skill enhancement
Potentially Hidden • Recycling Revenue • Product disposition cost	Energy Consumption • Life-cycle energy • Power use during operation	Peace of Mind • Perceived risk • Complaints
Contingent • Employee injury cost • Customer warranty cost	Local Impacts • Product recyclability • Impact upon local streams	Illness & Disease Reduction • Illnesses avoided • Mortality reduction
Relationship • Loss of goodwill due to customer concerns • Business interruption due to stakeholder interventions	Regional Impacts • Smog creation • Acid rain precursors • Biodiversity reduction	Accident & Injury reduction • Lost-time injuries • Reportable releases • Number of incidents
Externalities • Ecosystem productivity loss • Resource depletion	Global Impacts • CO_e emissions • Ozone depletion	Health & Wellness • Nutritional value provided • Food costs

2.2.2 Benefits of Sustainability in Design

The environmental benefits of sustainability in design, as it applies to the prerequisites of Rouse, appeal to the sense of accountability. Ethics plays an important part "because of the impact designers have on [...] quality of life, the environment, and the future" (Russ, 2010). The "do-no harm" concept is an oath that many believe should be adopted by all designer; mainly because designers are responsible for balancing "the interests of clients, community, economics, the environment, end users, and regulators to synthesize a design" (Russ, 2010).

There are social benefits also when considering sustainability in design. As Magis and Shinn (2009) state, economics and environment are the main factors of sustainability that many focus on (Magis & Shinn, 2009). Albeit that the three factors are all inter-related, those two are easiest to define. Social sustainability is in fact, promoting social well-being. Magis & Shinn (2009) share that Robert Prescott-Allen (in 2001) "describes social well-being as the fulfillment of basic needs and the exercise of political, economic, and social freedoms". "Three traditions of research and practice add definition to the concept of social well-being and, hence, social sustainability: Human-Centered Development, Sustainability, and Community Well-Being" (Magis & Shinn, 2009). This theory supports that the social aspect of sustainability is an important part of human (user)-centered design.

In recent years, recycling has become a mainstay in everyday life; from homeowners filling their green recycle bins with plastics and cardboard, to offices encouraging employees to place their empty cans and bottles in designated areas. Recycling of products is touted as being a solution towards sustainability. Some would say that recycling requires a certain social state of mind, a concern for the environment that influences an action. Carlson postulates that, "recyclers get either intrinsic satisfaction for doing the right thing, approval from friends and neighbors for their environmentally correct behavior, or both" (Carlson, 2001). Many recycle without receiving compensation or being told recycling is mandatory.

On the contrary, product manufacturers are held to a different standard; "regulations may force manufacturers to recycle even before the process becomes economically viable. Because the products to be recycled a few years from now are the ones designed and built today, we need to account for their recyclability in our current design process" (Beardsley, Kroll, & Parulian, 1996). Due to this potential regulation, it behooves manufactures to consider recycling and reclamation as additions to the design process.

A concept that Beardsley et al suggest is "design for disassembly", or "DFD", closely related to the well-known "design for assembly", or "DFA". While the aim of DFA is to simply the product so that the cost of assembly is reduced (Chan & Salustri, 2003), Beardsley et al suggest that DFD would encourage redesign of certain products so that disassembling them at their end of life would be conducive towards recycling.

In 2002, William McDonough and Michael Braungart, an architect and chemist, respectively, introduced to the world the idea of "cradle to cradle". Normally, a product's life cycle is "cradle to grave", where the grave is usually a landfill. McDonough and Braungart introduced their new concept as a charge to designers to remake the way things are made.

Albeit that recycling is a noble effort, it usually leads to lower quality materials that will eventually lead to their final resting place in a landfill. Instead, "products can be designed from the outset so that, after their useful lives, they will provide nourishment for something new" (McDonough & Braungart, 2002). The guiding principle of McDonough and Braungart is that "waste equals food". An excerpt from the book *Cradle to Cradle* shares that at the end of a product's life cycle, it becomes

> "'biological nutrients' that will easily reenter the water or soil without depositing synthetic materials and toxins. Or they can be 'technical nutrients' that will continually circulate as pure and valuable materials within closed-loop industrial cycles, rather than being 'recycled' - really, downcycled - into low-grade materials and uses" (McDonough & Braungart, 2002).

The "cradle to cradle" principle should be considered for the design process, because it factors from the beginning, what the product should consist of material wise, as well as what will happen with the materials at the end of life for the product. This principle is a proactive approach to achieving sustainability in design.

2.3 Gaps Between Sustainability and User-Centered Design

The goal of the research is to address the gaps between an accepted user-centered design process and sustainability factors to add to the model to ensure the design of products and systems meet the user's needs, expectations, and engagement with products and systems. Figure 5 illustrates the research gaps identified in the literature review and the contributions gained from conducting this research.

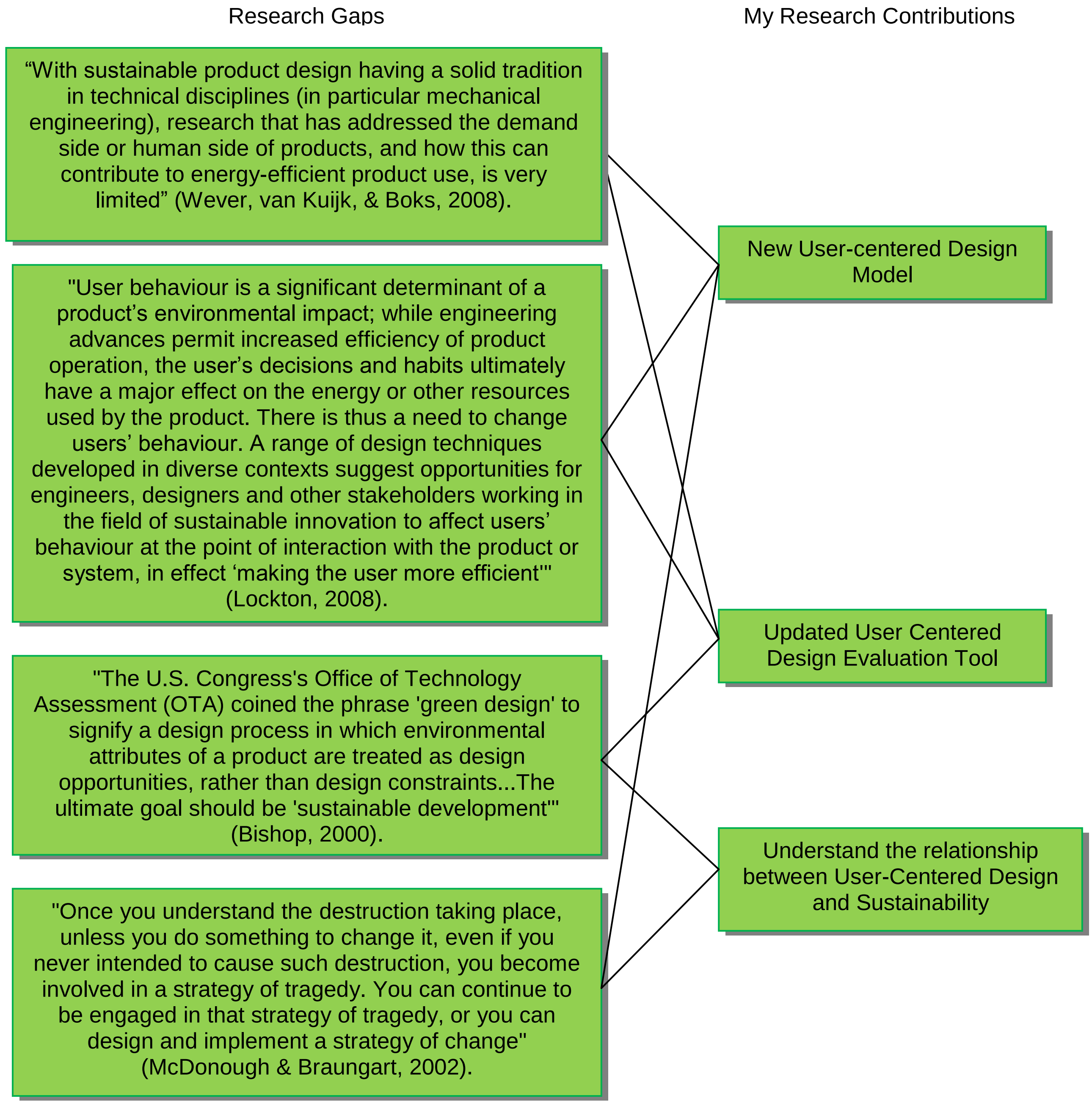

Figure 5: Research Gaps between User-Centered Design and Sustainability

CHAPTER 3: PROPOSED METHODOLOGY

This chapter discusses the objectives of this research, the development of the model integrating sustainability into the user-centered design process, the validation of sustainability integration for each factor (economical, environmental, and social) and the creation of a Sustainable Design Evaluation Tool to append to the User Centered Design Evaluation Tool developed by Meza. Additionally, this chapter states the products used to conduct the research.

3.1 Research Objectives

The purpose of this research is to integrate the three primary aspects of sustainability into an existing methodology of user-centered design. The objective is to create a hybrid model based on user-centered design, but also focusing on sustainability. Additionally, the use of three sustainability factors to develop a Sustainable Design Evaluation Tool, appended to the tool developed by Meza.

Sustainability is comprised of three factors: those factors are social, environmental, and economical. The goal is to emphasize the importance of sustainability, while suggesting intertwining sustainability into the process user-centered design. It is important to address the international standard of the design process, aptly titled human-centered design, instead of user-centered design. The International Organization for

Standardization (ISO) defines the development cycle for the human-centered design process in six steps (ISO 13407: Human-centered design process) (UsabilityNet: Methods: ISO 13407, 2006):

1. Identify need for human centered design
2. Specify context of use
3. Specify requirements
4. Produce design solutions
5. Evaluate designs
6. System satisfies specified requirements

Figure 6 shows the relationship of the six steps of the process. It is important to note that the process loops at the "Evaluate designs" phase and returns to "Specify context of use" until the system meets the requirements specified.

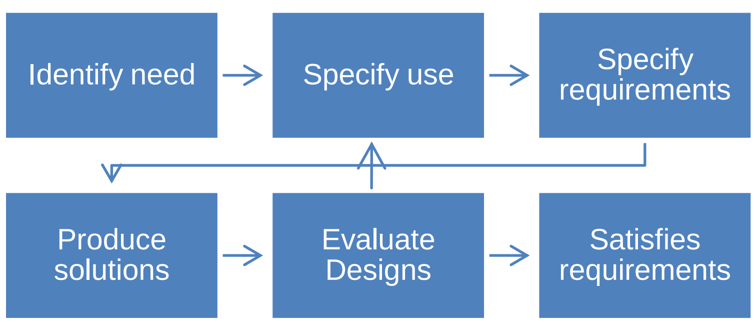

Figure 6: ISO 13407: Human-centered design process (UsabilityNet: Methods: ISO 13407, 2006)

The current methodology of user-centered design is well known and as stated by the Usability Professionals' Association follows a four-phase process: analysis, design, implementation, and deployment (Usability Professionals' Association, 2011), as shown in Figure 7.

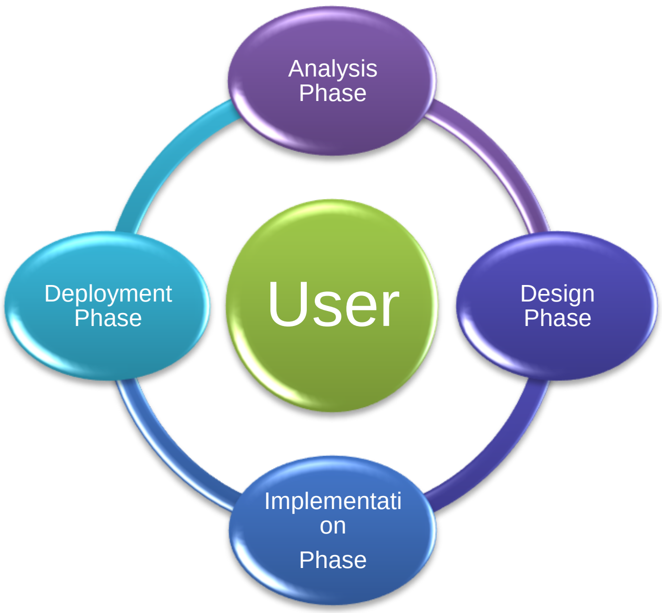

Figure 7: User-centered design process

The hybrid model developed in this research uses the four-phase user-centered design process as the main components and expands on the sub-components, utilizing the methodologies of two well-known organizations.

The steps taken to achieve objectives in this research were part of a four-phase process. The phases outline the research approach to achieve goals and objectives in this research. Figure 8 depicts the four phases and the accompanying objectives. The goal of Phase 1 was to characterize the components and sub-components for the user-centered design model integrating sustainability. Achievement of this objective was through literature review. Phase 2 objective was to select the appropriate tool to assess the components and sub-components. The next phase, Phase 3, the objective was to develop a tool to quantify the components and sub-components. The final phase, Phase 4, is to validate the research objectives.

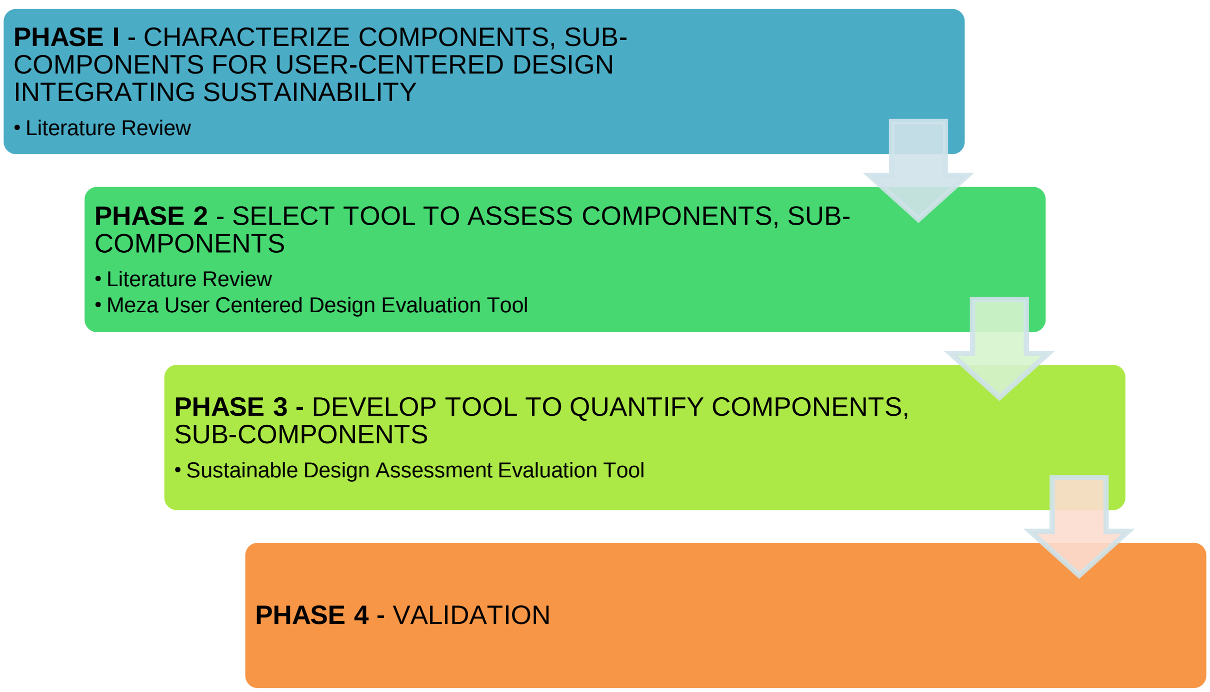

Figure 8: Major Phases of Research Objectives

3.2 Characterize Components and Sub-Components

Sustainability factors of importance as evidenced by the existing literature were incorporated into the research model generated during this research effort. The main components are the same as components of the user-centered design model outlined by the Usability Professionals' Association. The sub-components of the hybrid model developed in this research are a mixture of the methodology followed by the National Aeronautics and Space Administration (NASA) (Planning, Concept Design, Detailed Design, Production, Maintenance (National Aeronautics and Space Administration, 2011)) and SAP Software Solutions (Plan, Research, Design, Adapt, Measure (SAP, 2009)). The sub-components shown in Figure 9 have the additional components for sustainability; thus, the model is named User-Centered Design for Sustainability (UCDS). The sustainability components shown in Figure 9 have asterisks to differentiate from the usual sub-components of user-centered design.

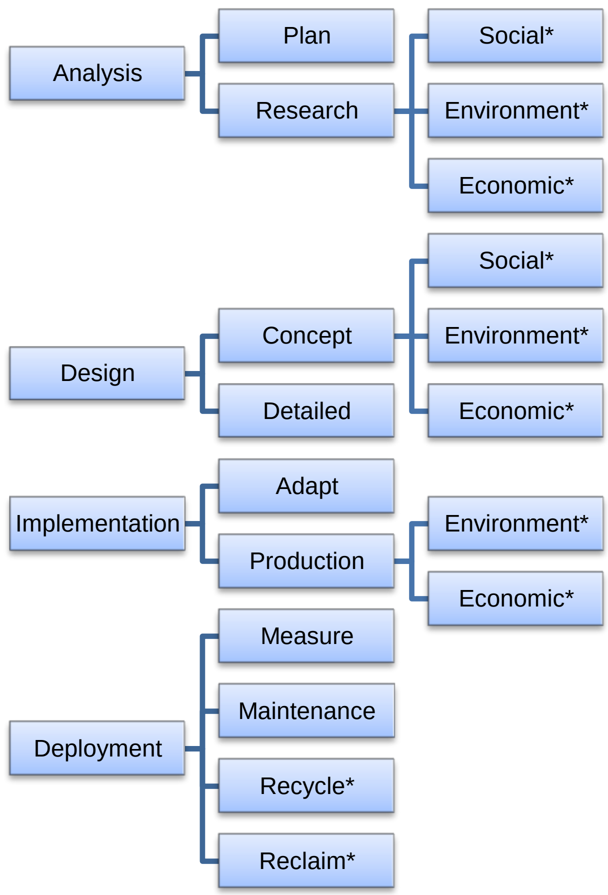

Figure 9: User-centered design for Sustainability (UCDS) methodology

The rationale for incorporating the three primary aspects of sustainability into the different phases of the user-centered design process is to ensure when designing a product or system, application of considerations for sustainability are throughout the process. In order for this to happen, weaving the three sustainability factors into the traditional user-centered design process is necessary. This is achieved by showing how and where each factor fits into the UCD process. Evidence from existing literature led to the development of the sustainability sub-components in this research and development of an evaluation tool for sustainable design.

3.2.1 Environmental Sustainability in User-Centered Design

Environmental sustainability is the easiest factor to integrate in user-centered design, because it is the most known aspect of sustainability. The environmental factor of sustainability is most useful in three categories of the user-centered design model. As seen in Figure 9, the components of environment sustainability are in included, which encompass analysis, design, and deployment.

The goal is to determine where the product or system fits, if at all, into the environmental factors that makes up sustainability. The following questions meet the research objectives to determine if the product or system meets the goals of environment al sustainability.

1. Is the product easy to disassemble?
2. Does the product come with sufficient information for recovery by the original equipment manufacturer (OEM) or third party?
3. Does the product come with minimal packaging?
4. Does the product design allow for all or parts of the product to be recycled?

A goal of this research is to incorporate these questions into a Sustainable Design Evaluation Tool, along with the two other factors of sustainability. Next is an examination of economic sustainability to determine how it fits into the user-centered design model, much like how environmental sustainability fits into the model.

3.2.2 Economical Sustainability in User-Centered Design

Using the literature as a basis, this research develops how economic sustainability fits into user-centered design; the rationale of the research states economic sustainability often examines the relationship between the consumer (user) and the producer. Understanding the user's needs and being able to meet those needs with a product or system leads to higher sales and a larger profit. The following questions meet the research objectives to determine if the product or system meets the goals of economic sustainability.

1. Does the development of the product include a risk management plan?
2. Does the manufacture of the product take into consideration stakeholder returns?
3. Does the manufacture of the product support profitable growth?
4. Is the product innovative?

3.2.3 Social Sustainability in User-Centered Design

It is clear to see that it is necessary to consider social sustainability early in the UCD process to take into account all of the social factors. This is why placement of social sustainability is in the Analysis phase of the model (shown in Figure 9). The challenge for engineers and designers is to determine where their product fits, if at all, into the societal considerations pertinent to sustainability. Social sustainability is the hardest of the three factors to define. Even literature describing sustainability factors has limited details on social sustainability. The following questions attempt to fill the gap in literature and meet the research objectives to determine if the product or system meets the goals of social sustainability.

1. Does the product support Equal Opportunity use?
2. Does the product meet the goal for its intended population?
3. Does the product foster an awareness of community?
4. Does the product come with sufficient information to educate the user with product use?

One technique to determine if the design of a product meets the criteria of user-centered design is to utilize evaluation tools and rate how the product meets the needs. Based on the information gained from the three components of sustainability, an evaluation tool (sustainable design) was developed, incorporating knowledge about sustainability to complete the user-centered design evaluation.

3.3 Evaluation Tools

In order to verify the UCDS model stated in the previous section, an additional evaluation tool was added to the User Centered Design Evaluation Tool introduced by Meza (2008). The questions stated in the social sustainability, environmental sustainability and economic sustainability sections of this research were used to develop the Sustainable Design Evaluation Tool. The evaluation tool created in this research joins the other evaluation tools from Meza's User Centered Design Evaluation Tool: cognitive design, industrial design, physical design, and user experience design. Tables 5-8 show the evaluation created by Meza. Table 9 is the Sustainable Design Evaluation Tool developed in this research.

Table 5: Cognitive Design Evaluation Tool (Meza, 2008)

COGNITIVE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
EASE OF USE									
The design uses population stereotypes that users can relate	NA	1	2	3	4	5	6	7	
Tasks/Procedures required are consistent	NA	1	2	3	4	5	6	7	
Tasks/Procedures required are intuitive	NA	1	2	3	4	5	6	7	
New tasks/Procedures required are easy to learn	NA	1	2	3	4	5	6	7	
Small amount of time required to learn how to perform a task	NA	1	2	3	4	5	6	7	
Features are familiar	NA	1	2	3	4	5	6	7	
MEMORABILITY									
Memorability – Maximum number of items a person needs to remember is between 5-9	NA	1	2	3	4	5	6	7	
Sensory storage-encoding (visual, auditory)	NA	1	2	3	4	5	6	7	
Coding – For high accuracy identification the number of colors used on a display are 5. Red, yellow, and green are reserved for “danger”, “caution”,	NA	1	2	3	4	5	6	7	

COGNITIVE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
and "safe", respectively.									
Working memory (short term – capacity, duration: visual, phonetic, semantic)	NA	1	2	3	4	5	6	7	
Long term memory – Steps and items can be remembered easily after a long period of time	NA	1	2	3	4	5	6	7	
USABILITY									
Short performance time is required to complete a task	NA	1	2	3	4	5	6	7	
Short amount of time is required to locate specific information	NA	1	2	3	4	5	6	7	
Output/Input – Large percentage of tasks successfully completed	NA	1	2	3	4	5	6	7	
Small number of times help is required	NA	1	2	3	4	5	6	7	
Small number of errors made performing a task	NA	1	2	3	4	5	6	7	
Short time spent recovering from errors	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

Table 6: Industrial Design Evaluation Tool (Meza, 2008)

INDUSTRIAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
FORM									
Color contrast ratio – Ration of object luminance over the background luminance. Measured with Modular Transfer Function Area (MTFA). High contrast must be 10 MTFA.	NA	1	2	3	4	5	6	7	
Appearance – Durable yet attractive finish	NA	1	2	3	4	5	6	7	
Font size – Observer's visual angle should be between 14-22 minutes of arc	NA	1	2	3	4	5	6	7	
Size of alert – Visual signals should subtend at least 1 degree of visual angle	NA	1	2	3	4	5	6	7	
Contrast ratio – Visual signals are at least twice as bright as other displays	NA	1	2	3	4	5	6	7	
Touchscreen sensor Size 19 mm square	NA	1	2	3	4	5	6	7	
Touchscreen size has a matrix of 5x6 or 6x7	NA	1	2	3	4	5	6	7	
Meets design requirements for the shape (length, width, height)	NA	1	2	3	4	5	6	7	
Meets design requirements for the texture (coarse, fine, even)	NA	1	2	3	4	5	6	7	
Design provides flexibility	NA	1	2	3	4	5	6	7	

INDUSTRIAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
(design allowances, tolerances, universal design considerations)									
SOUND/NOISE LEVEL									
Duration of signal sounds are appropriate for receival and recognition	NA	1	2	3	4	5	6	7	
Maximum signal levels – Level of auditory signal is 30 dB above masking threshold	NA	1	2	3	4	5	6	7	
Alarm signal minimum duration is 100ms	NA	1	2	3	4	5	6	7	
Pitch – The pitch of warming sounds is between 15-1000Hz	NA	1	2	3	4	5	6	7	
ILLUMINATION/LIGHTING									
Adaptation	NA	1	2	3	4	5	6	7	
Limited exposure to extreme radiant energy	NA	1	2	3	4	5	6	7	
Limited exposure to extreme irradiance	NA	1	2	3	4	5	6	7	
Limited exposure to extreme glare	NA	1	2	3	4	5	6	7	
Limited exposure to extreme brightness	NA	1	2	3	4	5	6	7	
Limited exposure to extreme reflectance	NA	1	2	3	4	5	6	7	
Limited exposure to extreme energy	NA	1	2	3	4	5	6	7	
VIBRATION									

INDUSTRIAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
Limited exposure to extreme vibration frequency	NA	1	2	3	4	5	6	7	
Limited exposure to extreme vibration intensity	NA	1	2	3	4	5	6	7	
Amplitude	NA	1	2	3	4	5	6	7	
Displacement	NA	1	2	3	4	5	6	7	
Limited exposure to impact forces	NA	1	2	3	4	5	6	7	
Velocity	NA	1	2	3	4	5	6	7	
Acceleration	NA	1	2	3	4	5	6	7	
TEMPERATURE									
Limited exposure to extreme environmental temperature	NA	1	2	3	4	5	6	7	
Limited exposure to extreme surface temperature	NA	1	2	3	4	5	6	7	
FUNCTION									
Features are consistent	NA	1	2	3	4	5	6	7	
Features are durable	NA	1	2	3	4	5	6	7	
Easy maintenance – Easy to clean	NA	1	2	3	4	5	6	7	
Features are precise	NA	1	2	3	4	5	6	7	
Features are comfortable	NA	1	2	3	4	5	6	7	
Features are predictable	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

Table 7: Physical Design Evaluation Tool (Meza, 2008)

PHYSICAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
ANTHROPOMETRY									
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Length (Width, Circumference)	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Mass (Volume, Weight, Density)	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Center of Mass	NA	1	2	3	4	5	6	7	

PHYSICAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
The design accommodates the 95th percentile male and the 5th percentile female of the population Range of Motion	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Strength Capabilities	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Moments	NA	1	2	3	4	5	6	7	
Muscular Activity can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
STRENGTH NEEDED									
Neutral body position	NA	1	2	3	4	5	6	7	
Isometric contraction can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	

PHYSICAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
Isotonic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Isokinetic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Static strength required can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Isoinertial condition	NA	1	2	3	4	5	6	7	
REPETITIVE MOTION									
Moderate tendon motion	NA	1	2	3	4	5	6	7	
Moderate tendon sheaths motion	NA	1	2	3	4	5	6	7	
Moderate muscles motion	NA	1	2	3	4	5	6	7	
Moderate ligaments motion	NA	1	2	3	4	5	6	7	
Moderate joints	NA	1	2	3	4	5	6	7	

PHYSICAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
motion									
Moderate nerves motion	NA	1	2	3	4	5	6	7	
MUSCULAR ACTIVITY									
Minimum static loading	NA	1	2	3	4	5	6	7	
Moderate endurance requirement	NA	1	2	3	4	5	6	7	
Moderate repetition requirement	NA	1	2	3	4	5	6	7	
Moderate frequency requirement	NA	1	2	3	4	5	6	7	
BODY POSTURE									
Neutral body plane	NA	1	2	3	4	5	6	7	
Neutral extension (No twisting required while extending)	NA	1	2	3	4	5	6	7	
Neutral flexion (No twisting required while flexing the muscles)	NA	1	2	3	4	5	6	7	
Neutral abduction	NA	1	2	3	4	5	6	7	
Neutral adduction	NA	1	2	3	4	5	6	7	
Neutral posture	NA	1	2	3	4	5	6	7	
BODY POSITION									
Neutral sitting position required	NA	1	2	3	4	5	6	7	
Neutral standing position required	NA	1	2	3	4	5	6	7	
Limited stooping required	NA	1	2	3	4	5	6	7	
Limited crouching required	NA	1	2	3	4	5	6	7	
Supine (lying down)	NA	1	2	3	4	5	6	7	

PHYSICAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
Limited kneeling required	NA	1	2	3	4	5	6	7	
Walking	NA	1	2	3	4	5	6	7	
Limited overhead reaching required	NA	1	2	3	4	5	6	7	
Activation is easy	NA	1	2	3	4	5	6	7	
Limited extended reach required	NA	1	2	3	4	5	6	7	
Signal levels – Signal levels are 15-16 dB above masking threshold for rapid response to a signal	NA	1	2	3	4	5	6	7	
Location of alert – 15 degrees of maximum deviation for high priority alerts and 30 degrees for low priority alerts	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

Table 8: User Experience Design Evaluation Tool (Meza, 2008)

USER EXPERIENCE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
EASE OF USE									
The design is helpful	NA	1	2	3	4	5	6	7	
The design is supporting	NA	1	2	3	4	5	6	7	
USABLE									
The design is enjoyable to use	NA	1	2	3	4	5	6	7	
The design is handy to use	NA	1	2	3	4	5	6	7	
The design is practical	NA	1	2	3	4	5	6	7	
The design is convenient	NA	1	2	3	4	5	6	7	
The design provides control	NA	1	2	3	4	5	6	7	
FINDABLE									
The design is predictable	NA	1	2	3	4	5	6	7	
The design is clear to use	NA	1	2	3	4	5	6	7	
The design is familiar	NA	1	2	3	4	5	6	7	
DESIRABLE									
The design is emotionally fulfilling	NA	1	2	3	4	5	6	7	
The design is satisfying	NA	1	2	3	4	5	6	7	
The design is motivating	NA	1	2	3	4	5	6	7	
The design is aesthetically pleasing	NA	1	2	3	4	5	6	7	
The design is entertaining to use	NA	1	2	3	4	5	6	7	
The design is	NA	1	2	3	4	5	6	7	

USER EXPERIENCE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
interesting to use									
The design is exciting to use	NA	1	2	3	4	5	6	7	
The design is attractive	NA	1	2	3	4	5	6	7	
The design is pleasant to use	NA	1	2	3	4	5	6	7	
CREDIBLE									
The design is comprehensible	NA	1	2	3	4	5	6	7	
The design is trustworthy	NA	1	2	3	4	5	6	7	
The design is reliable	NA	1	2	3	4	5	6	7	
ACCESSIBLE									
The design is simple to use	NA	1	2	3	4	5	6	7	
The design is inviting	NA	1	2	3	4	5	6	7	
VALUABLE									
The design is rewarding	NA	1	2	3	4	5	6	7	
The design is impressive	NA	1	2	3	4	5	6	7	
The design is innovative	NA	1	2	3	4	5	6	7	
The design is good creativity	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

The development of this tool is designed to meet the goal outlined in this research and capture the designers' perceptions of how well the product meets sustainable design goals. The Sustainable Design Evaluation Tool is fashioned after the evaluation tools developed by Meza (2008), so that the overall evaluation tool (integrated with this Sustainable Design Evaluation Tool) has continuity. The Sustainable Design Evaluation Tool is divided into three sections: social, environmental and economical. Each section addresses the questions previously stated in the social sustainability, environmental sustainability, and economical sustainability in user-centered design sections of this research.

Table 9: Sustainable Design Evaluation Tool

SUSTAINABLE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
SOCIAL									
The product supports Equal Opportunity use	NA	1	2	3	4	5	6	7	

SUSTAINABLE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
The product design meets its goal for intended population	NA	1	2	3	4	5	6	7	
The product fosters an awareness of community	NA	1	2	3	4	5	6	7	
The product comes with sufficient information for the user to educate themselves with product use	NA	1	2	3	4	5	6	7	
ENVIRONMENTAL									
The product is easy to disassemble	NA	1	2	3	4	5	6	7	
The product comes with sufficient information for recovery by OEM or third party	NA	1	2	3	4	5	6	7	
The product comes with minimal packaging	NA	1	2	3	4	5	6	7	
The product design allows for all or parts to be recycled	NA	1	2	3	4	5	6	7	
ECONOMICAL									

SUSTAINABLE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	Design Comments/Recommendation
The development of this product includes a risk management plan	NA	1	2	3	4	5	6	7	
The manufacture of this product takes into consideration stakeholder returns	NA	1	2	3	4	5	6	7	
The manufacture of this product supports profitable growth	NA	1	2	3	4	5	6	7	
The product is innovative	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

3.4 Data Collection

The User Centered Design Evaluation Tool developed by Meza, with the addition of the Sustainable Design Evaluation Tool developed in this research, were administered to participants for three types of products: residential flooring, medical device, and electronic device. The data was collected on how well the products met the expectations of the particular design area being assessed, in particular, cognitive design, industrial design, physical design, user experience design, and sustainable design. The reason for the addition of the Sustainable Design Evaluation Tool is to evaluate if sustainability aspects are captured during the design process. The ultimate goal is for engineers and designers to use the hybrid model prior to a performed evaluation, so that the product would reflect exceeding expectations in the sustainability areas of economics, environment, and social.

The three products evaluated are the following: Shaw© Living Carpet Tile (flooring), OneTouch® Delica™ Lancing Device (medical device), and Garmin nüvi 1450T GPS Navigator (electronic device). These products were selected for purposes of this research to reflect objects that participants would be familiar, to highlight products in different areas (electronic device, medical device, and flooring), as well as objects that represent different levels of sustainability, from the viewpoint of the researcher. Sustainability of the products prior to evaluation appear to be low (medical device), medium (flooring), and high (electronic device). The scale rating used in the evaluation tools (1 = “does not meet” to 7 = “exceeds”), are equivalent to the following values: low = 1 or 2, medium = 3, 4 or 5, and high = 6 or 7.

Each product was evaluated using the User Centered Design Product Evaluation Tools from Meza (2008), with the inclusion of the Sustainable Design Evaluation Tool, developed with the information collected in the literature review. The purpose of the Sustainable Design Evaluation Tool is to evaluate how products not previously designed using the hybrid user-centered design model fit sustainable expectations. The Sustainable Design Evaluation Tool adds the missing element to identify a product's degree of sustainability.

Figures 10-12 show the three evaluated products. Figure 10 is an image of the carpet tile produced by Shaw©. The intended use of the carpet is residential, with ease of installation due to the adhesive backing. This product was selected due to its perceived sustainability; traditional carpeting must be totally removed if worn or damaged, while the carpet tile is able to removed by one square if necessary (medium sustainability).

Figure 10: Shaw© Living Carpet Tile, Golden Wheat, 12"x12"

Figure 11 is an image of the OneTouch® lancing device and packaging. The intended use of the lancing device is to puncture the finger of persons with diabetes to draw blood for blood sugar testing. The selection of this product was due to its perceived sustainability; this product appears to have low sustainability, because due to its size, users may easily lose or break the product, which results in high disposal.

Figure 11: Lancing Device Packaging and Device (product not shown to scale with packaging in photo)

Figure 12 is an image of the Garmin nüvi 1450T GPS Navigator and packaging. The intended use of the product is a navigational tool to assist its user with directions, whether in a vehicle or on foot. The tool is able to provide navigation for roads in the United States and Canada. The selection of this product is due to its high perception of sustainability. Due to the technology of the GPS, the maps are updated electronically; therefore, the only reason to dispose of the product is damage or inability to charge.

Figure 12: GPS Navigator Packaging and Device (product not shown to scale with packaging in photo)

Ten participants from various backgrounds were selected to participate in the evaluations. The participants were selected due to availability to complete the evaluation. The majority of participants are students at the University of Central Florida, with the exception of two. Half of the participants completed the evaluation in a research office at the University of Central Florida and the other participants conducted the evaluation in a residential setting. The environment for both groups was quiet with no distractions.

Each participant was asked to take as much time as needed to become familiar with the three products. Participants were able to read accompanying literature as well as test the products and see how they worked. After the participants were familiar with the products, instructions for the evaluation were delivered. Each participant was given instruction to complete the evaluation to the best of their knowledge; participants were delivered the evaluations in the same order for product and evaluation tool.

The product order was carpet tile, lancing device, and GPS navigator. The order used for each participant in regards to the evaluation tools is as follows: cognitive design, industrial design, physical design, industrial design, user experience design, and sustainable design. The proctor timed each participant as they completed each evaluation; participants rated each product based on how the product met expectations of each design evaluation, on a scale from 1 to 7. Participants were also instructed to place any comments in the comments/recommendations columns of each evaluation tool. Table 10 gives details of the scale equivalencies for each evaluation tool.

Table 10: Scale used to rate product design

Product Requirements Expectation Scale	
Requirement/Expectation	**Scale**
Not Applicable	NA
Does Not Meet	1
Barely Meets	2
Somewhat Meets	3
Meets	4
Strongly Meets	5
Very Strongly Meets	6
Exceeds	7

CHAPTER 4: RESULTS

This chapter discusses the research results of the user centered design evaluations, using five evaluation tools (four tools developed by Meza and one tool developed in this research) which revealed the following demographics for the ten participants: age, sex, educational level and expertise in product design. Of the 10 participants, 60% were in the 18-24 age groups, 20% were in the 25-31 age groups, 10% were in the 32-38 age groups, and 10% were in the 39-45 age group. Figure 13 shows a chart of the percentages of each age group. Additional demographics of the evaluation participants include the percentage of each sex: 80% female, 20% male. The educational background of the participants ranged from some high school to some graduate school. The participants were also classified into two groups, novice and expert; novices were classified as having no background in human factors and ergonomics and experts have some background in human factors and ergonomics.

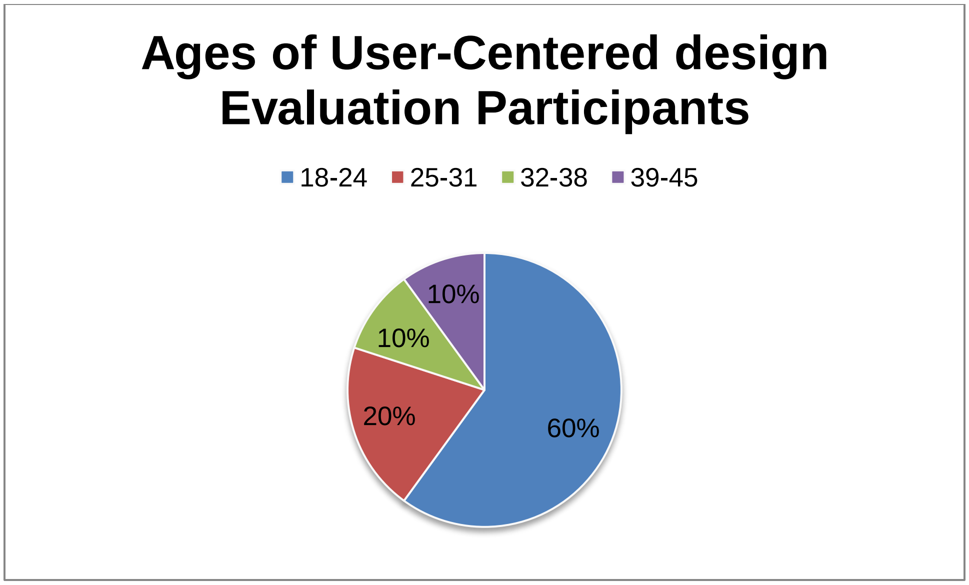

Figure 13: Range of ages of ten user-centered design evaluation participants

Tables 11-13 are the results for average time to complete the evaluations for each tool. The tables follow the same format as Meza, in order make comparisons of results. Meza's format to reflect time results were separated into three categories: novice average, expert average, and overall average. The time averages were for each evaluation tool. Meza used the following products in her research study: blood pressure monitor, blender, learning toy, GPS system and chair. The products Meza used can be separated into the following categories: medical device, electronics, and household furniture. The rationale behind choosing the products in this research was to select products that were similar to Meza's products.

The participants were given the evaluations in order of product and evaluation tool. Each participant evaluated the three products in the same order and each evaluation was given in the same order to each participant. The order the products were evaluated were carpet, lancing device, and GPS navigator. The order the evaluation tools were delivered to the participants was cognitive design, industrial design, physical design, user experience design, and sustainable design. One of the most notable results from the evaluations is that as the participants became familiar with the tools, the time to complete the evaluations decreased. This is similar to Meza's findings (2008), where she stated that "the values decrease significantly for both novice and expert users as the participant became familiar with using the evaluation tools.

Table 11: Time to Complete Evaluations: Product - Carpet

Evaluation Tool	Novice Average (minutes)	Expert Average (minutes)	Overall Average (minutes)
Cognitive Design	4.321	3.330	4.026
Industrial Design	3.263	4.413	4.038
Physical Design	2.462	4.347	3.404
User Experience Design	1.550	1.423	1.262
Sustainable Design	1.191	1.333	1.262

The differences in time between novice and expert participants when evaluating the carpet for cognitive, industrial, physical, user experience and sustainable design are 0.991, -1.150, -1.885, 0.127, and -0.142, respectively.

Table 12: Time to Complete Evaluations: Product - Lancing Device

Evaluation Tool	Novice Average (minutes)	Expert Average (minutes)	Overall Average (minutes)
Cognitive Design	1.335	1.288	1.311
Industrial Design	2.114	2.190	2.152
Physical Design	2.273	2.189	2.231
User Experience Design	1.192	1.281	1.236
Sustainable Design	1.047	1.049	1.048

The differences in time between novice and expert participants when evaluating the lancing device for cognitive, industrial, physical, user experience and sustainable design are 0.047, -0.076, 0.084, -0.089, and -0.002, respectively.

Table 13: Time to Complete Evaluations: Product - GPS Navigator

Evaluation Tool	Novice Average (minutes)	Expert Average (minutes)	Overall Average (minutes)
Cognitive Design	1.174	1.168	1.171
Industrial Design	2.173	2.474	2.323
Physical Design	1.478	2.150	2.014
User Experience Design	0.538	1.107	1.022
Sustainable Design	0.576	1.015	0.595

The differences in time between novice and expert participants when evaluating the GPS Navigator for cognitive, industrial, physical, user experience and sustainable design are 0.006, -0.301, -0.672, -0.569, and -0.439, respectively. Overall, average completion times for all three products used in this research are shown in Table 14.

Table 14: Average completion time for all products

Evaluation Tool	Average Completion Time	
	Novice Average (minutes)	Expert Average (minutes)
Cognitive Design	2.277	1.929
Industrial Design	2.517	3.026
Physical Design	2.071	2.895
User Experience Design	1.093	1.270
Sustainable Design	0.938	1.132

The differences in time between novice and expert for Meza's results are shown in Table 15. According to her research, it appears that, in general, the novice evaluators averaged more time in completing the evaluations than the expert evaluators.

Table 15: Time differences between Novice and Expert evaluators (Meza, 2008)

Evaluation Tool	Product	Novice Average (minutes)	Expert Average (minutes)	Difference (minutes)
	Blood Pressure Monitor			
Cognitive Design		3.013	2.097	0.916
Industrial Design		8.692	6.329	2.363
Physical Design		9.358	6.510	2.848
User Experience Design		5.271	2.097	3.174
	Blender			
Cognitive Design		1.913	1.487	0.426
Industrial Design		4.267	4.277	-0.010
Physical Design		4.842	4.777	0.065
User Experience Design		2.425	1.993	0.432
	Learning Toy			
Cognitive Design		1.688	1.317	0.371
Industrial Design		3.021	2.203	0.818
Physical Design		3.483	2.973	0.510
User Experience Design		1.850	1.863	-0.013

Evaluation Tool	Product	Novice Average (minutes)	Expert Average (minutes)	Difference (minutes)
	GPS System			
Cognitive Design		1.513	2.043	-0.530
Industrial Design		2.900	1.913	0.987
Physical Design		3.896	2.130	1.766
User Experience Design		1.829	1.263	0.566
	Chair			
Cognitive Design		0.929	0.960	-0.031
Industrial Design		1.742	1.730	0.012
Physical Design		3.650	1.667	1.983
User Experience Design		1.796	1.497	0.299

In Meza's research, she found that the physical design evaluation tool took the longest to complete, with an average completion time of 9.358 minutes. On the contrary, in this research, the evaluation tool that took the longest to complete was industrial design, for both novices and experts. The differences in values between this research and Meza may be due to the level of expertise of the participants. In general, the participants in this study who had some level of expertise with user-centered design took longer to perform the evaluations, as opposed to Meza’s research where the novice evaluators, on average had more completion times. Another difference to point out, the participants in this study who were experts, were not designers with years of experience working in their field as in Meza’s research, but instead students with some knowledge of user-centered design.

The evaluation tools used a scale from "1" to "7" to evaluate how the products met the design goals; "1" equals "Does Not Meet" requirement/expectation and "7" equals "Exceeds" requirement/expectation. The tables in sections 4.1 through 4.3 represent the overall averages, expert averages, and novice averages based on the evaluation tool scale for each product. Participants were also encouraged to provide any design comments or recommendations in the side columns provided on each evaluation tool.

4.1 Carpet

Tables 16-20 represent the cognitive design, industrial design, physical design, user experience design, and sustainable design averages from the evaluation tools for the carpet sample. The carpet used in this research is most comparable to the chair used in Meza's research. The justification for this rationale is they are both household (or residential) products and exhibit high use.

Table 16: Results from Cognitive Design Evaluation Tool - Carpet

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
EASE OF USE			
The design uses population stereotypes that users can relate	3.3	4.4	2.2

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Tasks/Procedures required are consistent	4	3.8	4.2
Tasks/Procedures required are intuitive	2.9	2.8	3
New tasks/Procedures required are easy to learn	3.7	3.8	3.6
Small amount of time required to learn how to perform a task	4.4	4.8	4
Features are familiar	3.9	4.6	3.2
MEMORABILITY			
Memorability – Maximum number of items a person needs to remember is between 5-9	2.7	3.2	2.2
Sensory storage-encoding (visual, auditory)	3.2	3.4	3
Coding – For high accuracy identification the number of colors used on a display are 5. Red, yellow, and green are reserved for “danger”, “caution”, and “safe”, respectively.	1	2	0
Working memory (short term – capacity, duration: visual, phonetic, semantic)	1.8	1.8	1.8
Long term memory – Steps and items can be remembered easily after a long	2.2	1.4	3

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
period of time			
USABILITY			
Short performance time is required to complete a task	3.4	4.2	2.6
Short amount of time is required to locate specific information	2.8	2.6	3
Output/Input – Large percentage of tasks successfully completed	2.3	3.4	1.2
Small number of times help is required	3	2.8	3.2
Small number of errors made performing a task	2.9	4.8	1
Short time spent recovering from errors	2.7	4.4	1

Table 17: Results from Industrial Design Evaluation Tool - Carpet

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
FORM			
Color contrast ratio – Ration of object luminance over the background luminance. Measured with Modular Transfer Function Area (MTFA). High contrast must be 10 MTFA.	1.2	2.4	0
Appearance – Durable yet attractive finish	5	5	5
Font size – Observer's visual angle should be between 14-22 minutes of arc	0.5	0	1
Size of alert – Visual signals should subtend at least 1 degree of visual angle	0.3	0	0.6
Contrast ratio – Visual signals are at least twice as bright as other displays	0.8	1	0.6
Touchscreen sensor Size 19 mm square	0.3	0	0.6
Touchscreen size has a matrix of 5x6 or 6x7	0.1	0	0.2
Meets design requirements for the shape (length, width, height)	3.4	4.8	2
Meets design requirements for the texture (coarse, fine, even)	4.5	4.4	4.6
Design provides flexibility (design allowances, tolerances, universal design considerations)	4.4	4	4.8

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
SOUND/NOISE LEVEL			
Duration of signal sounds are appropriate for receival and recognition	0	0	0
Maximum signal levels – Level of auditory signal is 30 dB above masking threshold	0	0	0
Alarm signal minimum duration is 100ms	0	0	0
Pitch – The pitch of warming sounds is between 15-1000Hz	0	0	0
ILLUMINATION/LIGHTING			
Adaptation	1.7	3.4	0
Limited exposure to extreme radiant energy	0.9	1.8	0
Limited exposure to extreme irradiance	0.5	1	0
Limited exposure to extreme glare	0.4	0.8	0
Limited exposure to extreme brightness	0.2	0.4	0
Limited exposure to extreme reflectance	0.4	0.8	0
Limited exposure to extreme energy	0.8	1.6	0
VIBRATION			

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Limited exposure to extreme vibration frequency	1.7	2.6	0.8
Limited exposure to extreme vibration intensity	1.3	1.8	0.8
Amplitude	0	0	0
Displacement	0.5	1	0
Limited exposure to impact forces	0.9	1	0.8
Velocity	0.3	0	0.6
Acceleration	0.3	0.6	0
TEMPERATURE			
Limited exposure to extreme environmental temperature	2.4	3.8	1
Limited exposure to extreme surface temperature	2.6	3.4	1.8
FUNCTION			
Features are consistent	5.4	5.4	5.4
Features are durable	4.9	5.2	4.6
Easy maintenance – Easy to clean	5.3	5.6	5
Features are precise	4.4	4.4	4.4

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Features are comfortable	5	5.6	4.4
Features are predictable	5	5.4	4.6

Table 18: Results from Physical Design Evaluation Tool - Carpet

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
ANTHROPOMETRY			
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Length (Width, Circumference)	1.2	2.4	0
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Mass (Volume, Weight, Density)	1.2	2.4	0
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Center of Mass	0.6	1.2	0
The design accommodates the 95th percentile male and the 5th percentile female of the population Range of Motion	1.1	2.2	0
The design accommodates the 95th percentile male and the 5th percentile female of the population Strength Capabilities	1.6	3.2	0.8
The design accommodates the 95th percentile male	0.6	1.2	0

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
and the 5th percentile female of the population Moments			
Muscular Activity can be performed by 95th percentile male and the 5th percentile female of the target population	1.6	2.2	1
STRENGTH NEEDED			
Neutral body position	2.1	2.4	2.6
Isometric contraction can be performed by 95th percentile male and the 5th percentile female of the target population	1.1	1.8	0.4
Isotonic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	1.1	1.8	0.4
Isokinetic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	1.1	1.8	0.4
Static strength required can be performed by 95th percentile male and the 5th percentile female of the target population	1.5	2.4	0.6
Isoinertial condition	1.1	1.8	0.4

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
REPETITIVE MOTION			
Moderate tendon motion	2.1	3.4	0.8
Moderate tendon sheaths motion	1.9	3	0.8
Moderate muscles motion	2.1	3.4	0.8
Moderate ligaments motion	2	3.2	0.8
Moderate joints motion	2.1	3.4	0.8
Moderate nerves motion	1.6	2.4	0.8
MUSCULAR ACTIVITY			
Minimum static loading	1.8	2.8	0.8
Moderate endurance requirement	1.9	2.8	1
Moderate repetition requirement	2.2	3	1.4
Moderate frequency requirement	2.4	4	1.6
BODY POSTURE			
Neutral body plane	1.6	2.4	0.8
Neutral extension (No twisting required while extending)	1.7	2.6	0.8

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
Neutral flexion (No twisting required while flexing the muscles)	1.7	2.6	0.8
Neutral abduction	0.9	1.8	0
Neutral adduction	1	2	0
Neutral posture	1.5	2.2	0.8
BODY POSITION			
Neutral sitting position required	1.2	1	1.4
Neutral standing position required	0.9	1	0.8
Limited stooping required	1.3	1.8	0.8
Limited crouching required	1.1	1.4	0.8
Supine (lying down)	1.4	1.4	1.4
Limited kneeling required	1.9	2.2	1.6
Walking	1.5	2.2	0.8
Limited overhead reaching required	0.9	1.8	0
Activation is easy	2.5	3	2
Limited extended reach required	0.7	1.4	0

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
Signal levels – Signal levels are 15-16 dB above masking threshold for rapid response to a signal	0	0	0
Location of alert – 15 degrees of maximum deviation for high priority alerts and 30 degrees for low priority alerts	0.4	0.8	0

Table 19: Results from User Experience Design Evaluation Tool - Carpet

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
EASE OF USE			
The design is helpful	5.1	4.8	5.4
The design is supporting	4.2	4.2	4.2
USABLE			
The design is enjoyable to use	5	4.2	5.8
The design is handy to use	5.4	5	5.8
The design is practical	5.5	5.2	5.8
The design is convenient	5.2	4.6	5.8
The design provides control	4.7	5.2	4.2
FINDABLE			
The design is predictable	5.7	5.6	5.8
The design is clear to use	5.7	5.8	5.6
The design is familiar	5.3	5	5.6
DESIRABLE			

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
The design is emotionally fulfilling	3.6	3.6	3.6
The design is satisfying	3.8	4.8	2.8
The design is motivating	3	3.4	2.6
The design is aesthetically pleasing	3.8	5	2.6
The design is entertaining to use	3.4	2.8	4
The design is interesting to use	4.3	4	4.6
The design is exciting to use	3.7	3.8	3.6
The design is attractive	4.3	4.8	3.8
The design is pleasant to use	4.7	4.6	4.8
CREDIBLE			
The design is comprehensible	4.3	5	3.6
The design is trustworthy	3.7	4.4	3
The design is reliable	4.5	4.4	4.6
ACCESSIBLE			
The design is simple to use	5.5	5.4	5.6

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
The design is inviting	4	4.6	3.4
VALUABLE			
The design is rewarding	3.3	4	2.6
The design is impressive	4.6	5	4.2
The design is innovative	4.8	5	4.6
The design is good creativity	4.9	5	4.8

Table 20: Results from Sustainable Design Evaluation Tool - Carpet

SUSTAINABLE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
SOCIAL			
The product supports Equal Opportunity use	4.9	4.6	5.2
The product design meets its goal for intended population	5.5	5.6	5.4
The product fosters an awareness of community	2	3.8	0.2
The product comes with sufficient information for the user to educate themselves with product use	4.4	4.6	4.2
ENVIRONMENTAL			
The product is easy to disassemble	4.2	5	3.4
The product comes with sufficient information for recovery by OEM or third party	2.2	3	1.4
The product comes with minimal packaging	3.6	4.8	2.4
The product design allows for all or parts to be recycled	3	3	3
ECONOMICAL			
The development of this product includes a risk management plan	1.2	1.6	0.8
The manufacture of this product takes into consideration	1.7	2.2	1.2

SUSTAINABLE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
stakeholder returns			
The manufacture of this product supports profitable growth	2.6	2.4	2.8
The product is innovative	3.5	4.2	2.8

4.2 Lancing Device

Tables 21-25 represent the cognitive design, industrial design, physical design, user experience design, and sustainable design averages from the evaluation tools for the lancing device. The lancing device used in this research is most comparable to the blood pressure monitor used in Meza's research. The justification for this rationale is they are both medical devices used to gather information about the user.

Table 21: Results from Cognitive Design Evaluation Tool - Lancing Device

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
EASE OF USE			
The design uses population stereotypes that users can relate	3.9	4.2	3.6
Tasks/Procedures required are consistent	5	5.2	4.8
Tasks/Procedures required are intuitive	3.3	3.8	2.8
New tasks/Procedures required are easy to learn	4.4	4	4.8
Small amount of time required to learn how to perform a task	4.9	5	4.8
Features are familiar	4.2	3.8	4.6
MEMORABILITY			
Memorability – Maximum number of items a person needs to remember is between 5-9	4.2	4.4	4
Sensory storage-encoding (visual, auditory)	2.9	3.4	2.4
Coding – For high accuracy identification the number of colors used on a display are 5. Red, yellow, and green are reserved for “danger”, “caution”, and “safe”, respectively.	1.2	1.6	0.8

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Working memory (short term – capacity, duration: visual, phonetic, semantic)	3.6	3.8	3.4
Long term memory – Steps and items can be remembered easily after a long period of time	3.9	4	3.8
USABILITY			
Short performance time is required to complete a task	5	5.6	4.4
Short amount of time is required to locate specific information	4.8	5.2	4.4
Output/Input – Large percentage of tasks successfully completed	5	5.6	4.4
Small number of times help is required	5	5.6	4.4
Small number of errors made performing a task	4.5	4.8	4.2
Short time spent recovering from errors	4.1	3.8	4.4

Table 22: Results from Industrial Design Evaluation Tool - Lancing Device

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
FORM			
Color contrast ratio – Ration of object luminance over the background luminance. Measured with Modular Transfer Function Area (MTFA). High contrast must be 10 MTFA.	1.8	3	0.6
Appearance – Durable yet attractive finish	4.9	5.4	4.4
Font size – Observer's visual angle should be between 14-22 minutes of arc	3	4.4	1.6
Size of alert – Visual signals should subtend at least 1 degree of visual angle	1.3	2	0.6
Contrast ratio – Visual signals are at least twice as bright as other displays	1.5	2.4	0.6
Touchscreen sensor Size 19 mm square	0.2	0	0.4
Touchscreen size has a matrix of 5x6 or 6x7	0.1	0	0.2
Meets design requirements for the shape (length, width, height)	4.6	5	4.2
Meets design requirements for the texture (coarse, fine, even)	3.7	4	3.4
Design provides flexibility (design allowances, tolerances, universal design considerations)	3	2.8	3.2

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
SOUND/NOISE LEVEL			
Duration of signal sounds are appropriate for receival and recognition	1.8	2	1.6
Maximum signal levels – Level of auditory signal is 30 dB above masking threshold	0	0	0
Alarm signal minimum duration is 100ms	0	0	0
Pitch – The pitch of warming sounds is between 15-1000Hz	0	0	0
ILLUMINATION/LIGHTING			
Adaptation	0.6	1.2	0
Limited exposure to extreme radiant energy	0	0	0
Limited exposure to extreme irradiance	0	0	0
Limited exposure to extreme glare	0	0	0
Limited exposure to extreme brightness	0	0	0
Limited exposure to extreme reflectance	0	0	0
Limited exposure to extreme energy	0	0	0
VIBRATION			

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Limited exposure to extreme vibration frequency	2	3.2	0.8
Limited exposure to extreme vibration intensity	2	3.2	0.8
Amplitude	1.4	2.8	0
Displacement	1.5	3	0
Limited exposure to impact forces	1.7	2.8	0.6
Velocity	1.3	2.6	0
Acceleration	1.3	2.6	0
TEMPERATURE			
Limited exposure to extreme environmental temperature	1.6	2.2	1
Limited exposure to extreme surface temperature	1.6	2.2	1
FUNCTION			
Features are consistent	4.6	5.4	3.8
Features are durable	4.4	5	3.8
Easy maintenance – Easy to clean	5	4.6	5.4
Features are precise	5.4	5.2	5.6

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Features are comfortable	5.2	4.8	5.6
Features are predictable	5.3	5	5.6

Table 23: Results from Physical Design Evaluation Tool - Lancing Device

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
ANTHROPOMETRY			
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Length (Width, Circumference)	2.6	4.6	1.2
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Mass (Volume, Weight, Density)	1.8	3	0.6
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Center of Mass	1.3	2	0.6
The design accommodates the 95th percentile male and the 5th percentile female of the population Range of Motion	1.9	3.2	0.6
The design accommodates the 95th percentile male and the 5th percentile female of the population Strength Capabilities	2.7	4.8	1.4
The design accommodates the 95th percentile male	1.9	3.2	0.6

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
and the 5th percentile female of the population Moments			
Muscular Activity can be performed by 95th percentile male and the 5th percentile female of the target population	2.5	5	0.8
STRENGTH NEEDED			
Neutral body position	2.8	4.8	1.6
Isometric contraction can be performed by 95th percentile male and the 5th percentile female of the target population	2.2	3.6	1.6
Isotonic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	2.2	3.6	1.6
Isokinetic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	2.2	3.6	1.6
Static strength required can be performed by 95th percentile male and the 5th percentile female of the target population	2.8	4.8	1.6
Isoinertial condition	1.8	2.8	0.8

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
REPETITIVE MOTION			
Moderate tendon motion	2.9	4	2.6
Moderate tendon sheaths motion	2.6	4	2
Moderate muscles motion	3.9	5.2	3.4
Moderate ligaments motion	2.9	4	2.6
Moderate joints motion	3.5	5.2	2.6
Moderate nerves motion	2.9	4	2.6
MUSCULAR ACTIVITY			
Minimum static loading	3.5	4.2	3.8
Moderate endurance requirement	3.6	4.4	4
Moderate repetition requirement	3.6	4.4	3.8
Moderate frequency requirement	3.2	4.4	3
BODY POSTURE			
Neutral body plane	3.9	5	2.8
Neutral extension (No twisting required while extending)	4.1	5.4	2.8

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
Neutral flexion (No twisting required while flexing the muscles)	4.1	5.4	2.8
Neutral abduction	3.6	4.4	2.8
Neutral adduction	3.3	4.2	2.4
Neutral posture	4.1	5.4	2.8
BODY POSITION			
Neutral sitting position required	2.4	3	1.8
Neutral standing position required	2.2	1.8	2.6
Limited stooping required	1.8	2.4	1.2
Limited crouching required	1.8	2.4	1.2
Supine (lying down)	1.2	1.2	1.2
Limited kneeling required	2.1	2.4	1.8
Walking	1.2	1.2	1.2
Limited overhead reaching required	1.9	2.6	1.2
Activation is easy	3.5	4.2	2.8
Limited extended reach required	1.1	2.2	0

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
Signal levels – Signal levels are 15-16 dB above masking threshold for rapid response to a signal	0	0	0
Location of alert – 15 degrees of maximum deviation for high priority alerts and 30 degrees for low priority alerts	0	0	0

Table 24: Results from User Experience Design Evaluation Tool - Lancing Device

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
EASE OF USE			
The design is helpful	5.1	5.2	5
The design is supporting	5.1	5.2	5
USABLE			
The design is enjoyable to use	3.9	4.4	3.4
The design is handy to use	5.4	5.6	5.2
The design is practical	5.6	5.8	5.4
The design is convenient	5.5	5.6	5.4
The design provides control	5.5	5.6	5.4
FINDABLE			
The design is predictable	5.1	5	5.2
The design is clear to use	5	4.6	5.4
The design is familiar	5.1	4.8	5.4

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
DESIRABLE			
The design is emotionally fulfilling	3.2	3.2	3.2
The design is satisfying	4.1	4.4	3.8
The design is motivating	2.9	3.2	2.6
The design is aesthetically pleasing	2.7	3.6	1.8
The design is entertaining to use	2	1.6	2.4
The design is interesting to use	4.2	4.2	4.2
The design is exciting to use	2	1.8	2.2
The design is attractive	3.5	3.6	3.4
The design is pleasant to use	3	3.6	2.4
CREDIBLE			
The design is comprehensible	3.8	4	3.6
The design is trustworthy	4.2	4.2	4.2
The design is reliable	4.1	4.4	3.8
ACCESSIBLE			

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
The design is simple to use	5.2	5	5.4
The design is inviting	3	3.6	2.4
VALUABLE			
The design is rewarding	3.6	3.6	3.6
The design is impressive	3.4	3.6	3.2
The design is innovative	4.3	4	4.6
The design is good creativity	4.1	3.4	4.8

Table 25: Results from Sustainable Design Evaluation Tool - Lancing Device

SUSTAINABLE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
SOCIAL			
The product supports Equal Opportunity use	4.2	4.6	3.8
The product design meets its goal for intended population	4.9	5.8	4
The product fosters an awareness of community	3.3	3.4	3.2
The product comes with sufficient information for the user to educate themselves with product use	5.4	5.6	5.2
ENVIRONMENTAL			
The product is easy to disassemble	3.1	2.8	3.4
The product comes with sufficient information for recovery by OEM or third party	1.7	2	1.4
The product comes with minimal packaging	4.8	4.8	4.8
The product design allows for all or parts to be recycled	3.4	3.6	3.2
ECONOMICAL			
The development of this product includes a risk management plan	1.5	1.4	1.6
The manufacture of this product takes into consideration	2	2.8	1.2

SUSTAINABLE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
stakeholder returns			
The manufacture of this product supports profitable growth	2.2	2.4	2
The product is innovative	4	3.4	4.6

4.3 GPS Navigator

The GPS Navigator used in this research is most comparable to the GPS System used in Meza's research. Although not identical products, these products are the most similar of all the products evaluated in Meza's and this research; thus, allowing direct comparisons. Table 26 shows the differences in average times of evaluators in Meza's research and this research.

Table 26: Comparisons of average time, Meza vs. Brown research

	GPS System (Meza)			GPS Navigator (Brown)		
Assessment Tool	Novice Average (minutes)	Expert Average (minutes)	Overall Average (minutes)	Novice Average (minutes)	Expert Average (Minutes)	Overall Average (minutes)
Cognitive Design	1.513	2.043	1.838	1.174	1.168	1.171
Industrial Design	2.900	1.913	2.475	2.173	2.474	2.323
Physical Design	3.896	2.130	3.096	1.478	2.150	2.014
User Experience Design	1.829	1.263	1.544	0.538	1.107	1.022
Sustainable Design	N/A	N/A	N/A	0.576	1.015	0.595

Tables 27-31 represent the cognitive design, industrial design, physical design, user experience design, and sustainable design averages from the evaluation tools for the GPS Navigator.

Table 27: Results from Cognitive Design Evaluation Tool - GPS Navigator

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
EASE OF USE			
The design uses population stereotypes that users can relate	3.9	5	2.8
Tasks/Procedures required are consistent	4.3	5	3.6
Tasks/Procedures required are intuitive	3.5	4.6	2.4
New tasks/Procedures required are easy to learn	4.8	4.8	4.8
Small amount of time required to learn how to perform a task	4.4	4.6	4.2
Features are familiar	4.7	4.8	4.6
MEMORABILITY			
Memorability – Maximum number of items a person needs to remember is between 5-9	3.4	3	3.8
Sensory storage-encoding (visual, auditory)	3.7	3.8	3.6
Coding – For high accuracy identification the number of colors used on a display are 5. Red, yellow, and green are reserved for "danger", "caution", and "safe", respectively.	2.4	3.4	1.4

COGNITIVE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Working memory (short term – capacity, duration: visual, phonetic, semantic)	4.1	4.6	3.6
Long term memory – Steps and items can be remembered easily after a long period of time	4.1	4.6	3.6
USABILITY			
Short performance time is required to complete a task	4.3	4	4.6
Short amount of time is required to locate specific information	4.4	4.2	4.6
Output/Input – Large percentage of tasks successfully completed	4.3	4.6	4
Small number of times help is required	4.1	4.4	3.8
Small number of errors made performing a task	3.1	3.2	3
Short time spent recovering from errors	3.5	3.8	3.2

Table 28: Results from Industrial Design Evaluation Tool - GPS Navigator

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
FORM			
Color contrast ratio – Ration of object luminance over the background luminance. Measured with Modular Transfer Function Area (MTFA). High contrast must be 10 MTFA.	2.8	4.4	1.2
Appearance – Durable yet attractive finish	5.3	5.2	5.4
Font size – Observer's visual angle should be between 14-22 minutes of arc	4.2	5	3.4
Size of alert – Visual signals should subtend at least 1 degree of visual angle	2.3	2.4	2.2
Contrast ratio – Visual signals are at least twice as bright as other displays	3.9	4.6	3.2
Touchscreen sensor Size 19 mm square	4.5	4.6	4.4
Touchscreen size has a matrix of 5x6 or 6x7	4.7	5	4.4
Meets design requirements for the shape (length, width, height)	4.7	5	4.4
Meets design requirements for the texture (coarse, fine, even)	4.4	5	3.8
Design provides flexibility (design allowances, tolerances, universal design considerations)	3.9	4	3.8

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
SOUND/NOISE LEVEL			
Duration of signal sounds are appropriate for receival and recognition	4.8	5.2	4.4
Maximum signal levels – Level of auditory signal is 30 dB above masking threshold	2.9	2.6	3.2
Alarm signal minimum duration is 100ms	0.9	0.4	1.4
Pitch – The pitch of warming sounds is between 15-1000Hz	1.4	1.6	1.2
ILLUMINATION/LIGHTING			
Adaptation	3.4	4.4	2.4
Limited exposure to extreme radiant energy	2.4	2.4	2.4
Limited exposure to extreme irradiance	2.4	2.4	2.4
Limited exposure to extreme glare	2.8	2.4	3.2
Limited exposure to extreme brightness	2.8	3.2	2.4
Limited exposure to extreme reflectance	3.2	3.2	3.2
Limited exposure to extreme energy	2.4	2.4	2.4
VIBRATION			

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Limited exposure to extreme vibration frequency	1.9	2.4	1.4
Limited exposure to extreme vibration intensity	1.9	2.4	1.4
Amplitude	0.4	0.8	0
Displacement	0.5	1	0
Limited exposure to impact forces	1.2	1.6	0.8
Velocity	0.4	0.8	0
Acceleration	0.8	1.6	0
TEMPERATURE			
Limited exposure to extreme environmental temperature	2.6	2.2	3
Limited exposure to extreme surface temperature	2.5	2	3
FUNCTION			
Features are consistent	5.1	5.2	5
Features are durable	5	5	5
Easy maintenance – Easy to clean	5.2	5.4	5
Features are precise	5	5	5

INDUSTRIAL DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
Features are comfortable	4.7	5.2	4.2
Features are predictable	4.8	5.4	4.2

Table 29: Results from Physical Design Evaluation Tool - GPS Navigator

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
ANTHROPOMETRY			
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Length (Width, Circumference)	1.9	3.2	0.6
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Mass (Volume, Weight, Density)	2	3.4	0.6
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Center of Mass	1.3	2	0.6
The design accommodates the 95th percentile male and the 5th percentile female of the population Range of Motion	2.7	4.8	1.4
The design accommodates the 95th percentile male and the 5th percentile female of the population Strength Capabilities	2.3	4	1.4
The design accommodates the 95th percentile male	1.9	3.2	0.6

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
and the 5th percentile female of the population Moments			
Muscular Activity can be performed by 95th percentile male and the 5th percentile female of the target population	2.7	4.8	1.4
STRENGTH NEEDED			
Neutral body position	3.2	4.6	2.6
Isometric contraction can be performed by 95th percentile male and the 5th percentile female of the target population	2.1	3.6	1.6
Isotonic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	2.1	3.6	1.6
Isokinetic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	2.1	3.6	1.6
Static strength required can be performed by 95th percentile male and the 5th percentile female of the target population	2.2	3.8	1.6
Isoinertial condition	2.3	3.6	2

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
REPETITIVE MOTION			
Moderate tendon motion	3.4	4.4	3.2
Moderate tendon sheaths motion	2.8	3.8	2.6
Moderate muscles motion	3.5	3.8	4
Moderate ligaments motion	3.1	3.8	3.2
Moderate joints motion	3.3	4.2	3.2
Moderate nerves motion	3.2	3.8	3.4
MUSCULAR ACTIVITY			
Minimum static loading	3.3	5	2.4
Moderate endurance requirement	4.1	5	4
Moderate repetition requirement	3.2	4	3.2
Moderate frequency requirement	3	3.6	3.2
BODY POSTURE			
Neutral body plane	3.1	5	2.2
Neutral extension (No twisting required while extending)	3.7	4	2.8

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
Neutral flexion (No twisting required while flexing the muscles)	3.7	4	2.8
Neutral abduction	2	4	0.8
Neutral adduction	1.8	3.6	0.8
Neutral posture	2.8	4.4	2
BODY POSITION			
Neutral sitting position required	3.1	3.6	2.6
Neutral standing position required	2.4	2.4	2.4
Limited stooping required	1.4	1	1.8
Limited crouching required	1.4	1	1.8
Supine (lying down)	0.5	1	0
Limited kneeling required	1.1	1	1.2
Walking	1.2	1.8	0.6
Limited overhead reaching required	0.6	1.2	0
Activation is easy	4.5	5	4.8
Limited extended reach required	3.1	4.4	2.6

PHYSICAL DESIGN	AVERAGE	EXPERT	NOVICE
Signal levels – Signal levels are 15-16 dB above masking threshold for rapid response to a signal	2	3.2	1.6
Location of alert – 15 degrees of maximum deviation for high priority alerts and 30 degrees for low priority alerts	0.8	1.6	0

Table 30: Results from User Experience Design Evaluation Tool - GPS Navigator

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
EASE OF USE			
The design is helpful	5.1	5	5.2
The design is supporting	5.1	5	5.2
USABLE			
The design is enjoyable to use	5.1	5	5.2
The design is handy to use	5.1	5	5.2
The design is practical	5.3	5.4	5.2
The design is convenient	5.3	5.4	5.2
The design provides control	5.2	5.2	5.2
FINDABLE			
The design is predictable	5.2	5.4	5
The design is clear to use	5.2	5.2	5.2
The design is familiar	5.3	5.4	5.2
DESIRABLE			

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
The design is emotionally fulfilling	4.8	4.4	5.2
The design is satisfying	4.8	4.6	5
The design is motivating	3.9	4.2	3.6
The design is aesthetically pleasing	3.6	3.8	3.4
The design is entertaining to use	4.6	4	5.2
The design is interesting to use	4.5	3.8	5.2
The design is exciting to use	4.6	3.8	5.4
The design is attractive	4.1	4.2	4
The design is pleasant to use	5	4.6	5.4
CREDIBLE			
The design is comprehensible	4.2	4.6	3.8
The design is trustworthy	5	4.8	5.2
The design is reliable	5.2	5	5.4
ACCESSIBLE			
The design is simple to use	5.2	5	5.4

USER EXPERIENCE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
The design is inviting	4.4	4.8	4
VALUABLE			
The design is rewarding	4.2	4.6	3.8
The design is impressive	4.5	4.4	4.6
The design is innovative	4.7	4.2	5.2
The design is good creativity	4.4	3.6	5.2

Table 31: Results from Sustainable Design Evaluation Tool - GPS Navigator

SUSTAINABLE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
SOCIAL			
The product supports Equal Opportunity use	4.4	5	3.8
The product design meets its goal for intended population	4.6	5.2	4
The product fosters an awareness of community	3.2	3.6	2.8
The product comes with sufficient information for the user to educate themselves with product use	5.1	5.2	5
ENVIRONMENTAL			
The product is easy to disassemble	2	3.2	0.8
The product comes with sufficient information for recovery by OEM or third party	1.8	2.8	0.8
The product comes with minimal packaging	3.3	3.8	2.8
The product design allows for all or parts to be recycled	3.1	2	4.2
ECONOMICAL			
The development of this product includes a risk management plan	2	1.8	2.2

SUSTAINABLE DESIGN	OVERALL AVERAGE	EXPERT	NOVICE
The manufacture of this product takes into consideration stakeholder returns	2.9	3.6	2.2
The manufacture of this product supports profitable growth	2.7	2.4	3
The product is innovative	4.1	3.4	4.8

It is interesting to note, that areas where the value is "0" either meant that the particular design requirement/expectation was not applicable or the participant did not know what the design requirement/expectation meant; the latter was often the case with the novice participants who were not familiar with the terms.

CHAPTER 5: DISCUSSION AND CONCLUDING REMARKS

This chapter is a discussion of the research findings from the Sustainable Design Evaluation Tool developed. It also includes the contributions to the body of knowledge and future research opportunities resulting from this research.

5.1 Discussion

The purpose of this research was to develop a hybrid model of user-centered design integrating sustainability, create an updated version of Meza's User Centered Design Evaluation Tool, and provide understanding of the relationship between user-centered design and sustainability. The user-centered design for sustainability (UCDS) model was developed to be used as a guideline for incorporating sustainability into a traditional user-centered design model. The purpose of integrating sustainability into the process is to address the growing need for sustainable products and systems. By integrating the specific areas of sustainability (economic, environment, and social) into the model, it allows for designers and engineers to take into account sustainability from the onset of design, rather than the end. Implementing the hybrid model leads to a product or system that the user wants and is satisfied with, while additionally showing a commitment to the overall well-being of the community (economically, environmentally, and socially) in which the product or system will be used.

Furthermore, added to the User Centered Design Evaluation Tool developed by Meza (2008) was a Sustainable Design Evaluation Tool. The User Centered Design Evaluation Tool developed by Meza indentifies “quantitative measures to assess the significant factors of user-centered design” (Meza, 2008). The Sustainable Design Evaluation Tool enables designers and users to evaluate the product to ensure it is meeting sustainable needs, requirements, and expectations. The evaluation tools were used to evaluate products from three different categories: residential flooring, medical device, and electronic device. The reason for the various categories was to capture common everyday items of which users would be familiar and categories that would have varying levels of sustainability.

Table 32 details the averages of each product (carpet, lancing device, and GPS Navigator). Prior to the results of this study, the three products were ranked on their perceived ability to meet sustainable expectations. The carpet was ranked medium, the lancing device ranked low, and the GPS Navigator ranked high. The scale rating used in the evaluation tools (1 = “does not meet” to 7 = “exceeds”), are equivalent to the following values: low = 1 or 2, medium = 3, 4 or 5, and high = 6 or 7. It is difficult to determine if this research satisfies the objective that the Sustainable Design Evaluation Tool is a viable tool to assess sustainability factors, according to the results in Table 32. Further research and development of the Sustainable Design Evaluation Tool may support that it is a viable tool to assess sustainability factors.

Table 32: Overall averages of requirements/expectations of Sustainable Design Evaluation Tool

SUSTAINABLE DESIGN	OVERALL AVERAGES		
SOCIAL	Carpet	Lancing Device	GPS Navigator
The product supports Equal Opportunity use	4.9 (medium)	4.2 (medium)	4.4 (medium)
The product design meets its goal for intended population	5.5 (medium to high)	4.9 (medium)	4.6 (medium)
The product fosters an awareness of community	2 (low)	3.3 (medium)	3.2 (medium)
The product comes with sufficient information for the user to educate themselves with product use	4.4 (medium)	5.4 (medium to high)	5.1 (medium to high)
ENVIRONMENTAL			
The product is easy to disassemble	4.2 (medium)	3.1 (medium)	2 (low)
The product comes with sufficient information for recovery by OEM or third party	2.2 (low)	1.7 (low)	1.8 (low)
The product comes with minimal packaging	3.6 (medium)	4.8 (medium)	3.3 (medium)
The product design allows for all or parts to be recycled	3 (medium)	3.4 (medium)	3.1 (medium)
ECONOMICAL			
The development of this product includes a risk management plan	1.2 (low)	1.5 (low)	2 (low)
The manufacture of this product takes into consideration	1.7 (low)	2 (low)	2.9 (low to medium)

SUSTAINABLE DESIGN	OVERALL AVERAGES		
stakeholder returns			
The manufacture of this product supports profitable growth	2.6 (low to medium)	2.2 (low to medium)	2.7 (low to medium)
The product is innovative	3.5 (medium)	4 (medium)	4.1 (medium)

5.2 Contribution to Body of Knowledge

The purpose of this research was to contribute to the body of knowledge and fill gaps that are present in the current user-centered design process and sustainability. Some of the gaps that existed, based on the literature review, included limited availability of research in sustainable product design, a need to change user behavior by designing sustainable products and systems, and limited "strategies of change" towards sustainable development. The development of the hybrid model of user-centered design and Sustainable Design Evaluation Tool contribute to the research gaps by addressing the need for a "change in strategy", as well as influencing a traditional user-centered design model towards "green design", by integrating sustainability aspects into the pre-existing model. Below is a summary of the resulting research contributions:

- Increased understanding of the relationship between user-centered design and sustainability

- Development of user-centered design model for sustainability (UCDS)
- Development of qualitative descriptors to define sustainable components in user-centered design for sustainability (UCDS) model (Economical, Environmental, Social, Recycle, Reclaim)
- Creation of an evaluation tool for sustainable design (Sustainable Design Evaluation Tool) to enhance established evaluation tools evaluating cognitive design, industrial design, physical design, and user experience design
- Development of a quantitative tool for assessing the degree of sustainability design considerations present in products and systems

As stated in the literature review, Figure 14 represents the research gaps and contributions resulting from this research.

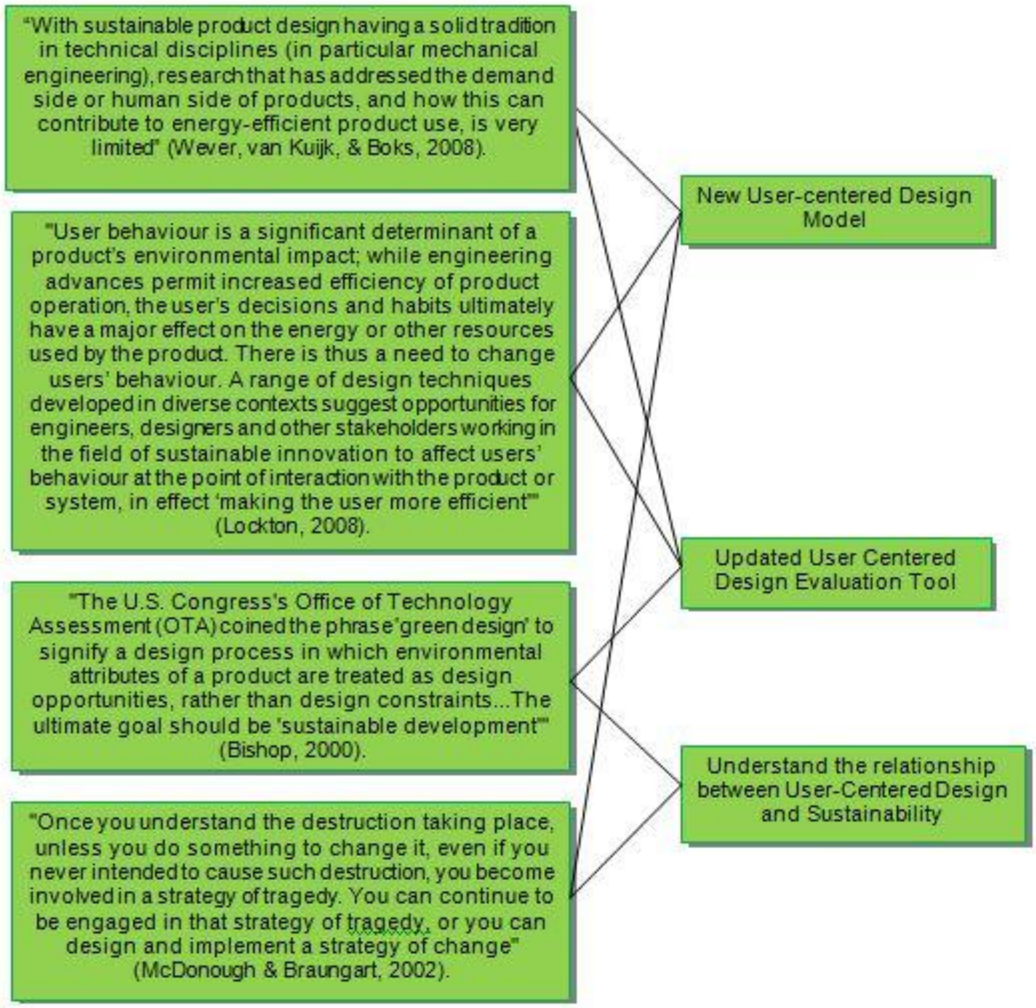

Figure 14: Research gaps and contributions to body of knowledge

5.3 Future Research

This research is a step towards incorporating sustainability into design, in particular user-centered design. Future research should include a larger data sample size to validate conclusions. In addition to a larger sample size, a more diverse population is needed for data validation. Incorporation of other sustainability models may also be a consideration for future research; additionally, consideration for comparison of additional models that are available.

Another research effort that should be included for future purposes is to analyze if the UCDS methodology has any positive differences in product and system design for capturing sustainable requirements and expectations. For instance, an organization in industry could develop the same product side-by-side with the traditional user-centered design methodology and determine the results. An option to encourage organizations to participate in future research is to automate the Sustainable Design Evaluation Tool; this could be achieved by creating software for the Sustainable Design Evaluation Tool.

Another area to consider for future research would be to incorporate the hybrid UCDS methodology into education, in particular engineering education, and use it as a tool for teaching future engineers and designers. Comparisons could be made to prior class projects administered by professors in user-centered design based courses and how project ideas change with implementation of the hybrid UCDS method.

Additional ways to improve the validity of this research include the development and incorporation of a technique to validate the evaluation tool. The technique should include a tool to assess the robustness of the tool given factors of product complexity.

Another way to improve validity is the development of a technique and/or equations to optimize the components of the Sustainable Design Evaluation Tool. This may be achieved by assigning weights to factors of the Sustainable Design Evaluation Tool. The opinion of subject matter experts (SME) is another consideration to verify this research, in particular the Sustainable Design Evaluation Tool.

Limitations encountered during the course of this research include deficiency of diversity in evaluation participants, time constraint, and limited number (small population) of evaluation participants. Steps to alleviate these limitations in future research consist of increasing the number of participants, in addition to obtaining a more diverse population to participate in the product evaluations. Another solution may include addressing the time constraint by allotting more time to conduct the research.

LIST OF REFERENCES

Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-Centered Design. In *W. Encyclopedia of Human-Computer Interaction.* Thousand Oaks: Sage Publications.

Apple, Inc. (2011). *The Story Behind Apple's Environmenal Footprint*. Retrieved October 22, 2011, from Apple: http://www.apple.com/environment/

Arup. (2011). *About Us*. Retrieved October 22, 2011, from Arup: http://www.arup.com/About_us.aspx

Arup. (2011). *Sustainability Consulting*. Retrieved October 22, 2011, from Arup: http://www.arup.com/Services/Sustainability_Consulting.aspx

Asefa, S. (2005). The Concept of Sustainable Development: An Introduction. In S. e. Asefa, *The Economics of Sustainable Development* (pp. 1-18). Kalamazoo: W.E. Upjohn Institute for Employment Research.

Beardsley, B., Kroll, E., & Parulian, A. (1996). A methodology to evaluate ease of disassembly for product recycling. *IIE Transactions* , 837.

Bishop, P. L. (2000). *Pollution Prevention: Fundamentals and Practice.* Boston: McGraw-Hill.

Blevis, E. (2007). Sustainable Interaction Design: Invention & Disposal, Renewal & Reuse. *Proceedings of the SIGCHI conference on Human factors in computing systems (CHI '07)* (pp. 503-512). New York: ACM.

Boeing. (2011). *Boeing in Brief Home*. Retrieved October 22, 2011, from Boeing: http://www.boeing.com/companyoffices/aboutus/brief.html

Boeing. (2011). *Commercial Airplanes - Overview Home*. Retrieved October 22, 2011, from Boeing: http://www.boeing.com/companyoffices/aboutus/brief/commercial.html

Bras, B. (1997). Incorporating Environmental Issues in Product Design and Realization. *Industry and Environment* .

Carlson, A. E. (2001). Recycling Norms. *California Law Review* , 1231-1300.

Chan, V., & Salustri, F. (2003). *Design for Assembly*. Retrieved September 29, 2011, from http://deed.ryerson.ca/~fil/t/dfmdfa.html

de Silva, N., Jawahir, I., Dillon Jr., O., & Russell, M. (2009). A new comprehensive methodology for the evaluation of product sustainability at the design and development stage of consumer electronic products. *International Journal of Sustainable Manufacturing* , 251-264.

Environmental Protection Agency. (2011). *History of Sustainability*. Retrieved October 2, 2011, from U.S. Environment Protection Agency: http://yosemite.epa.gov/r10/oi.nsf/8bb15fe43a5fb81788256b58005ff079/398761d6c3c7184988256fc40078499b!OpenDocument

Greenwood, T. (2011). *Sustainability*. Retrieved October 21, 2011, from espdesign.org: http://www.espdesign.org/sustainability-definition/

Hawkins, D. E. (2006). *Corporate social sustainability: Balancing tomorrow's sustainability and today's profitability.* New York: Palgrave Macmillan.

IBM® Design: UCD Process. (n.d.). Retrieved September 29, 2011, from IBM® Design: http://www-01.ibm.com/software/ucd/ucd.html

IDEO, Inc. (2011). *About IDEO*. Retrieved October 21, 2011, from IDEO: http://www.ideo.com/about/

IDEO, Inc. (2011). *Human-Centered Design Toolkit*. Retrieved October 22, 2011, from IDEO: http://www.ideo.com/work/human-centered-design-toolkit/

Kankainen, A. (2003). UCPCD: User-Centered Product Concept Design. *Proceedings of the 2003 conference on Designing for user experiences (DUX '03)* (pp. 1-13). New York: ACM.

Kuniavsky, M. (2003). *Observing the User Experience: A practitioner's guide to user research.* San Francisco: Morgan Kaufmann Publishers.

Kutz, M. (2007). *Environmentally Conscious Mechanical Design.* Hoboken: John Wiley & Sons.

Lockton, D. (2008). Making the user more efficient: Design for sustainable behaviour. *International Journal of Sustainable Engineering* , 3-8.

Magis, K., & Shinn, C. (2009). Emergent Principles of Social Sustainability. In J. Dillard, V. Dujon, & M. C. King, *Understanding the Social Dimension of Sustainability* (pp. 15-44). New York: Routledge.

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things.* New York: North Point Press.

Merriam-Webster, Incorporated. (2011). *Sustainability - Definition and More*. Retrieved October 4, 2011, from Dictionary and Thesaurus - Merriam-Webster Online: http://www.merriam-webster.com/dictionary/sustainability

Meza, K. I. (2008). *The creation of tools and models to characterize and quantify user-centered design considerations in product and system development.* Orlando: University of Central Florida.

National Aeronautics and Space Administration. (n.d.). *NASA - Process: Usability and User Centered Design Process*. Retrieved August 14, 2011, from NASA's Usability Toolkit: http://www.hq.nasa.gov/pao/portal/usability/process/index.htm

Norman, D. A. (1988). *The Psychology of Everyday Things.* New York: Basic Books.

Norman, D. A., & Draper, S. W. (1986). *User centered system design: New perspectives on human-computer interaction.* Hillsdale: Elrbaum Associates.

Pereira, T. (2009). Sustainability: An integral engineering design approach. *Renewable and Sustainable Energy Reviews* , 1133-1137.

Porta, S., & Renne, J. L. (2005). Linking urban design to sustainability: formal indicators of social urban sustainability field research in Perth, Western Australia. *Urban Design International* , 51-64.

Rouse, W. B. (1991). *Design for Success: A human-centered approach for designing successful products and systems.* New York: Wiley.

Russ, T. H. (2010). *Sustainability and Design Ethics.* Boca Raton: CRC Press, Taylor & Francis.

SAP. (2009, January 16). *SAP User-Centered Design*. Retrieved August 14, 2011, from SAP Design Guild: http://www.sapdesignguild.org/resources/ucd_process.asp

U.S. Green Building Council. (2011). Retrieved October 21, 2011, from USGBC: U.S. Green Building Council: www.usgbc.org

Usability Professionals' Association. (n.d.). *What is User-Centered Design*. Retrieved August 7, 2011, from About Usability: UPA Resources: http://www.upassoc.org/usability_resources/about_usability/what_is_ucd.html

UsabilityNet: Methods: ISO 13407. (2006). Retrieved October 14, 2011, from UsabilityNet: http://www.usabilitynet.org/tools/13407stds.htm

Van Velsen, L., Van der Geest, T., Klaasen, R., & Steehouder, M. (2008). User-centered evaluation of adaptive and adaptable systems: a literature review. *The Knowledge Engineering Review* , 261-281.

Wever, R., van Kuijk, J., & Boks, C. (2008). User-centred design for sustainable behaviour. *International Journal of Sustainable Engineering* , 9-20.

William McDonough Architects. (1992). *The Hanover Principles: Design for Sustainability*. Retrieved October 5, 2011, from William McDonough - Being Less Bad is Not Being Good: http://www.mcdonough.com/principles.pdf

World Commission on Environment and Development. (1987). *Our Common Future.* Oxford: Oxford University Press.