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A Method for Assessing the Sustainability of Design in Developing World Projects

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A METHOD FOR ASSESSING THE SUSTAINABILITY OF DESIGN IN DEVELOPING WORLD PROJECTS

by

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Table of Contents

List of Tables

List of Figures

Abstract

Projects for the developing world usually find themselves at the bottom of an engineer's priority list. There is often very little engineering effort placed on creating new products for the poorest people in the world. This trend is beginning to change now as people begin to recognize the potential for these projects. Engineers are beginning to try and solve some of the direst issues in the developing world and many are having positive impacts. However, the conditions needed to support these projects can only be maintained in the short term. There is now a need for greater sustainability.

Sustainability has a wide variety of definitions in both business and engineering. These concepts are analyzed and synthesized to develop a broad meaning of sustainability in the developing world. This primarily stems from the "triple bottom line" concept of economic, social, and environmental sustainability. Using this model and several international standards, this thesis develops a metric for guiding and evaluating the sustainability of engineering projects. The metric contains qualitative questions that investigate the sustainability of a project. It is used to assess several existing projects in order to determine flaws. Specifically, three projects seeking to deliver eyeglasses are analyzed for weaknesses to help define a new design approach for achieving better results.

Using the metric as a guiding tool, teams designed two pieces of optometry equipment: one to cut lenses for eyeglasses and the other to diagnose refractive error, or prescription. These designs are created and prototyped in the developed and developing

worlds in order to determine general feasibility. Although there is a recognized need for eventual design iterations, the whole project is evaluated using the developed metric and compared to the existing projects. Overall, the success demonstrates the improvements made to the long-term sustainability of the project resulting from the use of the sustainability metric.

Chapter 1: Introduction

One constant in our evolving world is the enormous financial gap between the wealthy and the poor. More than half of people in the world live on less than $10 a day while in places like the US where the minimum wage was $7.25 in 2011, people make almost that much in an hour [1,2]. People at the bottom of the economic pyramid struggle to survive let alone increase their income and improve their way of life. As a part of the growing global economy, it has recently become even more evident how destitute these people truly are. Despite this, most engineers continue to focus a majority of their efforts to develop goods for the top ten percent of the world's population [3]. Unfortunately, limited engineering effort is devoted to the people who need it most.

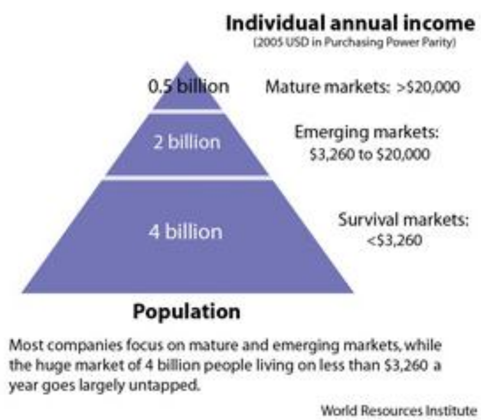


Figure 1-1 World Economic Pyramid [1]

Engineering efforts have sought to address many of the direst needs of people in developing areas of the world like medicine, shelter, and water [4,5]. However, many of these efforts have been difficult to sustain and were not ultimately successful in the long term. They often demanded periodic maintenance and typically required a large amount of knowledge and training that could not be found or easily provided in the developing world. Also, most did not provide opportunities for social or economic growth in the future. Ultimately, the goal in these parts of the world should be to gather the knowledge and tools necessary to grow and develop out of poverty, rather than obtain short-lived material possessions to solve immediate problems.

To assist in creating more sustainable solutions, engineers need to reconsider the design process and develop a more sustainable approach for solving problems in the developing world. Sustainability requires a strong consideration of the financial, social, and environmental resources available and how their use can assist in long-lasting development. In this thesis, the “triple bottom line” provides the basis for a set of engineering sustainability questions to better evaluate and guide design projects [6].

Chapter 2 presents a synthesis of concepts in engineering and business sustainability grounded in the “triple bottom line”. In chapter 3, we use several international sustainability standards as sources to develop a metric for gauging the sustainability of design projects. This metric includes a series of questions to evaluate projects on each of the three bottom lines. In chapter 4, we use these questions to evaluate existing projects to determine specific flaws. The results are presented in a matrix form to compare projects and determine common sustainability issues in developing world design.

This metric is ultimately used in chapter 4 to assess several projects aiming to bring prescription eyeglasses to the developing world. An estimated one billion people in the world are in need of corrective lenses, but do not have access to optometrists or eyeglasses [7]. In some parts of the world the ratio of optometrists to people can be as low as one to one million [8].

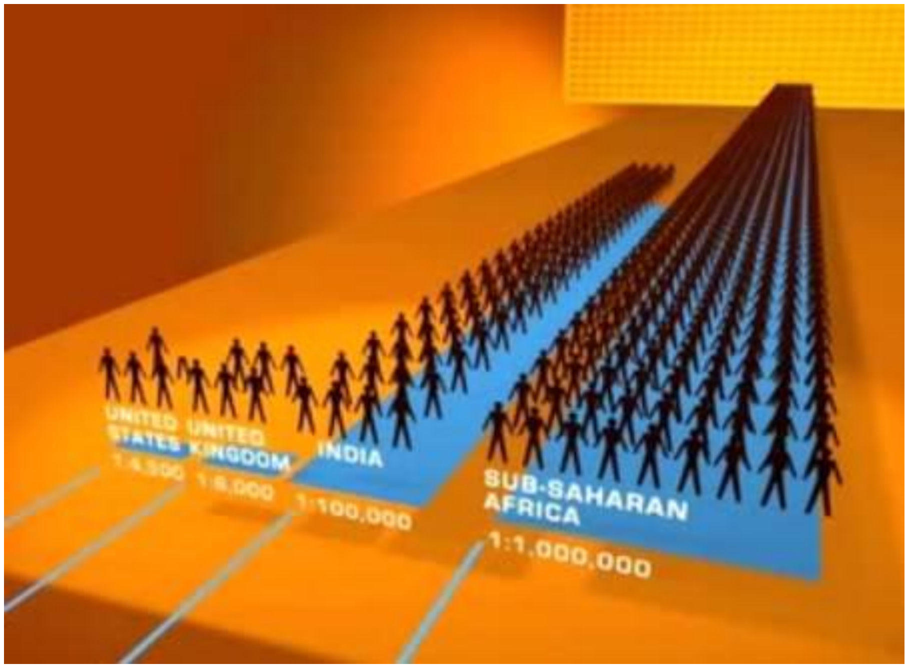


Figure 1-2 Ratio of Optometrists to People in Various Parts of the World [8]

Previous projects chose to redesign eyeglasses using adaptive lens technologies. However, this approach has been relatively unsuccessful, and thus a new method was devised in chapter 5. This new effort seeks to modify the existing system appropriately for the developing world. Thus, the project involved redesigning and prototyping two pieces of optometry equipment. This included testing, manufacturing, and redesign in a developing region of Guatemala.

Finally, in chapter 6, this thesis discusses the relative success of this project and the potential of the sustainability metric. These questions have a strong ability to indicate key flaws in previous attempts to solve developing world problems. They also allow designers to better focus their design efforts for sustainable development. Ultimately, they will lead to more sustainable endeavors as was seen in the new eyeglasses venture. Future applications of these questions will only lead to a greater substantiation of their successful use in developing world design projects.

1.1 References

[1] World Resources Institute, "June 2006 Monthly Update: The Base of the Economic Pyramid (BOP) | EarthTrends" 2011, http://earthtrends.wri.org/updates/node/50.

[2] U.S. Department of Labor, “Wages - Minimum Wage" 2011, http://www.dol.gov/dol/topic/wages/minimumwage.htm.

[3] "Design for the Other 90% | Cooper-Hewitt, National Design Museum" 2011, http://archive.cooperhewitt.org/other90/other90.cooperhewitt.org/.

[4] "D-Rev: Design Revolution " 2011, http://d-rev.org/index.html.

[5] "Design for the Other 90% | Cooper-Hewitt, National Design Museum" 2011, http://archive.cooperhewitt.org/other90/other90.cooperhewitt.org/.

[6] Savitz, A.W., “The triple bottom line,” Jossey-Bass, San Francisco, CA.

[7] “Centre for vision in the developing world,” 2011, http://www.vdwoxford.org/.

[8] Shakesville, “Shaker Thumbs" 2011, http://shakespearessister.blogspot.com/2009/09/shaker-thumbs_25.html.

Chapter 2: Sustainability

The meaning of sustainability has become blurred over the last several decades. In many cases it has become the buzzword of choice for corporations seeking to improve their image in the minds of their stakeholders. But this does not diminish the importance of true business and engineering sustainability in a rapidly evolving world. In 1983, the United Nations convened the World Commission on Environment and Development (WCED) to address a growing concern over the ability to develop socially and economically amidst the depletion of the environment and natural resources. In its report entitled *Our Common Future*, the WCED created one of the most widely recognized definitions of sustainability. It states “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1]. This encourages everyone to consider the long-term as well as the immediate impacts of their choices; people should consider how their actions will affect their future and the futures of their descendents.

Business people and engineers have adopted this mentality in similar and different ways. Both groups employ an array of practices in their efforts to promote sustainability. The question we seek to answer is how these practices can be utilized in the developing world. As these parts of the world continue to grow, they must do so in a way that does not jeopardize their future or the future of others. In this chapter we review sustainability from both perspectives and provide a synthesis of ideas and practices applicable to projects in the developing world.

2.1 Business

In the corporate world, sustainability has become an issue of strategy. Sustainability is seen as a “natural extension of other organizational changes”, where “over the last century, society has increasingly raised its expectations of business” [2]. Abraham Maslow developed a hierarchy of needs in his study of human motivation [3]. Over time, society has created a similar hierarchy of expectations for businesses.

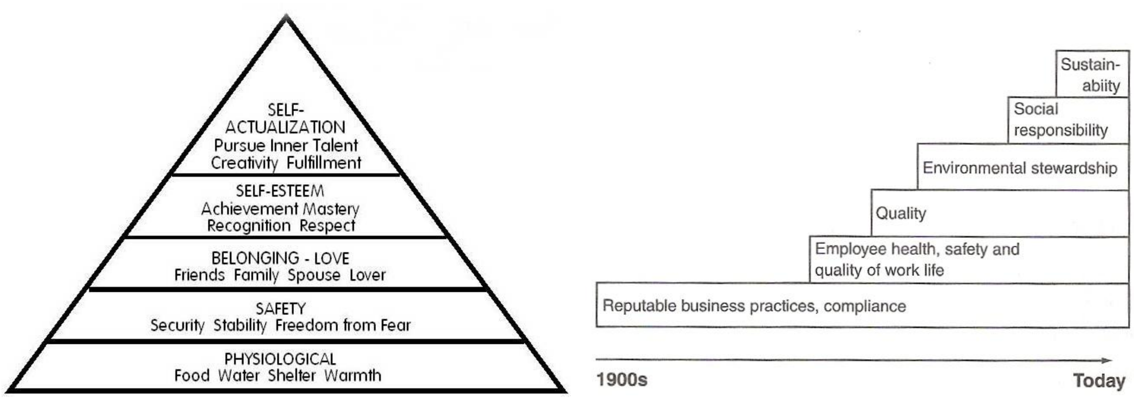


Figure 2-1 Maslow Hierarchy of Needs vs. Sustainability Hierarchy [3,2]

Whereas self-actualization is the ultimate goal for human motivation, businesses strive for sustainability. It is no longer acceptable to simply comply with laws and regulations that are often behind the times. Companies are expected to go above and beyond to reach the higher tiers of the pyramid and demonstrate true concern for people and nature, in addition to their own profits. This is more commonly recognized as the “triple bottom line”. The optimization of the economic, social, and environmental aspects is the key to sustainability.

The “bottom line” has always entailed earnings. A company’s success was measured by how much profit it made. This was the primary concern of shareholders, in addition to the next two tiers of the sustainability hierarchy, customer and employee satisfaction. However, corporations have begun to recognize new stakeholders including the local and worldwide communities directly or indirectly impacted by their decisions. This led to increased focus on the environmental stewardship and social responsibility tiers as they lead to the acme of total sustainability. The following sections describe concepts and corporate initiatives in each tier.

2.1.1 Environmental Stewardship

Sustainability buzzwords such as environmental stewardship, eco-effectiveness, and eco-efficiency revolve around a growing concern for the environment and our depletion of natural resources [4]. One of the most familiar terms is “greening”. A revolution has begun where people are inundated by mass media enlightening them on global warming, greenhouse gases, depletion of the ozone layer, energy-efficiency, and alternative energy [5]. Society’s concern has translated to business concern. Companies are more strongly considering how their products and processes could be influencing global warming and the environment in general.

In many cases changes have been proactive and come from the core of the company, leading to a need for fewer changes down the line and in the future. The Pollution Prevention Pays (3P) program at 3M is a great example of this mentality. “We think it’s better to prevent pollution than to try to clean it up later” [6]. “Product reformulation, process modification, equipment redesign, and recycling and reuse of waste materials" are just a few of the ways 3M has reduced its footprint [6]. Starbucks' policy of environmental stewardship has its employees working on improvements in its suppliers' coffee fields, its stores, its customers' consumption, and more. In its words, "as a company that relies on an agricultural product, it makes good business sense" [7].

2.1.2 Corporate Social Responsibility

In addition to the environment, companies must also consider community needs. Corporate social responsibility, corporate citizenship, and transparency are all buzzwords surrounding the social realm of sustainability. With the internet and other convenient ways to disseminate information, the active stakeholder bases of companies have become more knowledgeable. So companies must now recognize that their actions and the results of those actions are no longer secretive. This encourages "more effective stakeholder engagement" and the incorporation of "voices from the entire product lifecycle" [4].

Therefore, companies continually seek to understand how their business affects people down the line from its suppliers to its workers to its customers. In all cases, companies desire a harmonious relationship to ensure continued success. This results in a wide array of actions from philanthropic work to community-based development. Philanthropic work includes mostly monetary donations and aid. Although these are helpful in their own way, companies strive to integrate the company more into the community. For example, Shell is actively involved in the Flower Valley of South Africa. Through the Flower Valley Conservation Trust they have provided training in the sustainable harvesting of fynbos, a wild flower crucial to the economy of the region [8]. By doing so, they can help provide more economic and social sustainability, shared values of the company and community.

2.2 Engineering

Often the ability of a company to achieve its sustainability goals depends on the work of its engineers. Therefore, an engineer must be able to apply similar sustainable strategies. There is a clear link between the concepts discussed above and the tactics of engineers. Some of the most common sustainability models amongst engineers are cradle to cradle, life-cycle engineering, and reduce, reuse, recycle. These are all very closely related and all help to achieve the same result of minimal environmental and social impact through careful engineering.

The industrial revolution perpetuated a "cradle-to-grave" system where concern for a product only mattered from inception to disposal [9]. "Cradle-to-grave" meant that companies gave birth to products made from any number of Earth's resources and they would eventually end up "in a 'grave' of some kind, usually a landfill or incinerator" [9]. "According to some accounts more than 90% of materials extracted to make durable goods in the United States become waste almost immediately" [9]. This has led to a throw-away culture where we are comfortable with disposing of products with little concern for the environmental impact.

Recently, the concept of "cradle-to-cradle" design has become the solution to these problems resulting from the industrial revolution. These designs force engineers to consider not only how a product will be made and how it will be used but also how it will be discarded and how it can be used to make a new product. Instead of needing to use new material resources to create a new product, an old product can be reused or recycled instead. In many cases, only one or a few parts of a product break, rendering the product useless. Instead of throwing it away, replacing that one component or few components and refurbishing the product gives birth to another lifecycle. The ultimate goal is always to design a product that can be reborn at the end of its current life-cycle.

This idea has become known as life-cycle engineering. “Life-Cycle Engineering is a process to develop specifications to meet a set of performance, cost, and environmental requirements and goals that span the product, system, process, or facility life cycle” [10]. As seen in Figure 2-2, the lifecycle includes four major stages where material and energy use and waste are tracked. Most important for sustainability, the figure shows how a product at the end of its lifecycle can be looped back to a previous stage potentially reducing the raw material or energy needed as input.

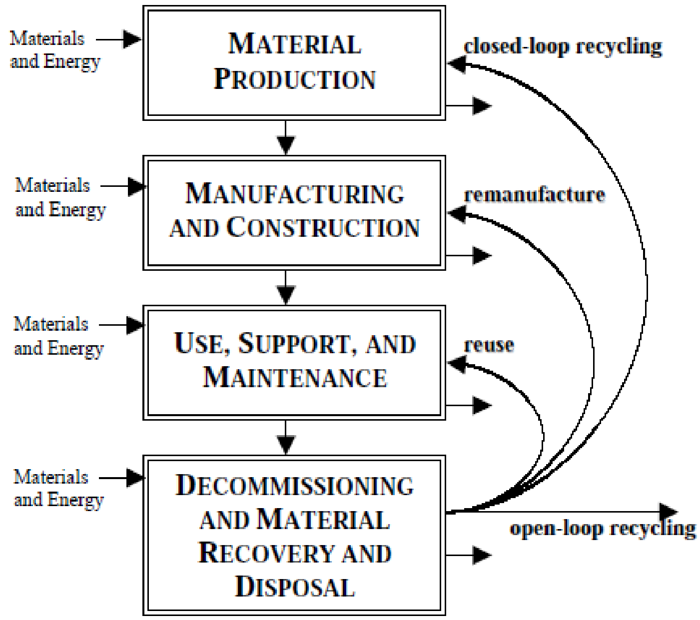


Figure 2-2 Lifecycle Stages [10]

These feedback loops are directly connected to the principles of reduce, reuse, and recycle. Although traditionally thought of as concepts for consumers, they can play a significant role in engineering. First and foremost, engineers seek to limit the amount of resources used in producing an item. This includes material, energy, time, and capital. This reduction not only benefits the environment but the business as well. “Reduce” is often the easiest of the three principles for the engineer to control. The engineer can also provide an opportunity for the consumer to reuse a product even though there is no guarantee it will happen. However, considering how a product can or will be reused whether for its original purpose, or another, is still important. Finally, it is worthwhile to make a product recyclable, even if it is more difficult to control how it can be recycled. Recycling is up to the consumer and based on a variety of constraints such as availability, convenience, and cost. It may not be easy or cheap for someone to recycle. But it is still the responsibility of the engineer to provide a product made from materials that can be recycled. Additionally, it can be beneficial for an engineer to design a product that can be made from the same recyclable materials. At the end of the product's lifetime, it can be reclaimed by the company and turned into a new product, saving the company valuable resources and money.

A good example of these strategies being implemented is in the design of purified water bottles, and specifically Aquafina's Eco-Fina bottle. This new bottle utilizes 50% less plastic than its predecessor. [11] The reduction in material theoretically saves the company close to 50% on the cost of the bottle. Like its competitors, this bottle is still sturdy enough to be reused by the consumer multiple times for a wide range of liquids. And finally, when the bottle is disposed of by the consumer, all of its components can be recycled. This includes the label, cap, and bottle. [11] So instead of ending up in a landfill, it can be converted into something new.

2.3 The Triple Bottom Line for Projects in the Developing World

While the ideas described above are used throughout the developed world, the resource constraints make it questionable how they can be directly translated to the developing world. Can businesses afford to have these concerns? Must engineers still consider the entire life-cycle, from cradle to cradle? We suggest the answer to these questions is yes, but conveniently everything can be condensed into one model, the triple bottom line [12]. For a venture to ultimately succeed in the developing world the triple bottom line must be considered. This will include both business and engineering sustainability concepts, simply tied together and focused into the three realms of finance, society, and the environment.

The ability to be financially sustainable is the biggest priority in regions seeking to develop and improve their quality of life. People in the developing world are mostly concerned with their ability to provide for their families; they work simply to be able to afford their necessities. However, projects must also attend to social and environmental impacts. In developing world communities there are social dynamics that must be dealt with like cultural norms and expectations, gender roles, education, etc. This is especially true when it comes to the local workforce and potential entrepreneurs for new businesses. From an environmental perspective there are often limited natural resources. Any project must make efficient use of these resources that are scarce and often expensive. Reusing and refurbishing components can also assist in attempts at environmental friendliness.

The lack of adherence to the triple bottom line mentality has led to limited success of products designed for the developing world. In chapter 3 we will provide an approach for synthesizing these sustainability concepts into the triple bottom line form. A metric will be provided for engineers to use in guiding the design process and eventually evaluate a product’s overall sustainability.

2.4 References

[1] World Commission on Environment and Development., 1990, "Our common future," Oxford University Press, Oxford; New York.

[2] Hitchcock, D.E., and Willard, M.L., 2006, "The business guide to sustainability : practical strategies and tools for organizations," Earthscan, London; Sterling, VA.

[3] McLeod, S., 2012, "Maslow hierarchy of needs," 2012, http://www.simplypsychology.org/maslow.html.

[4] Hart, S.L., 2007, "Capitalism at the crossroads : aligning business, earth, and humanity," Wharton School Pub., Upper Saddle River, N.J.

[5] Estes, J., 2009, "Smart green : how to implement sustainable business practices in any industry and make money," Wiley, Hoboken, N.J.

[6] 3M, "3P – Pollution Prevention Pays" 2011, http://solutions.3m.com/wps/portal/3M/en_US/3M-Sustainability/Global/Environment/3P/.

[7] Starbucks, "Being a Responsible Company" 2011, www.starbucks.com/responsibility.

[8] Flower Valley Conservation Trust, "Indigenous Cape Fynbos Plants South Africa " 2011, http://www.flowervalley.org.za/cgi-bin/giga.cgi?cmd=cause_dir_cause&cause_id=1866.

[9] McDonough, W., and Braungart, M., 2002, "Cradle to cradle : remaking the way we make things," North Point Press, New York.

[10] Cooper, J.S., and Vigon, B., 2001, “Life Cycle Engineering Guidelines,” Battelle Columbus Laboratories, Columbus, Ohio.

[11] "Aquafina - the Official Site " 2011, http://www.aquafina.com/.

[12] Savitz, A.W., “The triple bottom line,” Jossey-Bass, San Francisco, CA.

Chapter 3: Metric for Sustainability

Sustainability is crucial to development projects in order to ensure their long-lasting impact in the developing world. However, without appropriate metrics, it is difficult to evaluate sustainability. Some organizations provide guidelines for sustainable development and some engineers are beginning to explore the development of such metrics. In this chapter we review existing literature related to sustainability and evaluation criteria. We then develop a general sustainability metric composed of questions to guide and evaluate the sustainability of any engineering design project. Economic, social, and environmental sustainability are used as the three guiding categories. Utilizing information from three internationally recognized standards on sustainability, questions that would affect engineering design decisions were developed in each category. This chapter summarizes these standards and their intended use and explains the rationale behind each question.

3.1 Literature Review

The need for sustainable development has been recognized by a multitude of international organizations. Most notably, the United Nations formed the Commission on Sustainable Development (CSD). Over many years, the CSD worked with countries as well as governmental and non-governmental organizations to develop a set of sustainable development indicators [1]. After testing and evaluation, professional review, and many revisions, a core set of 50 indicators and a total of 96 were published in 1997 [1].

Accompanying these indicators are a set of methodology sheets that describe how the indicators are then used by countries in the development of programs to accomplish goals such as ending poverty, eradicating disease, and protecting the natural environment [1]. While these indicators provide quantitative information on a wide variety of areas, they are most applicable to governmental and nationwide efforts.

Engineers Without Borders (EWB), an organization providing engineering assistance to the developing world, has created its own guidelines for sustainable community development [2]. Since EWB works on a project specific basis, it has identified the need for a general approach and set of requirements. It identifies four “dimensions” of sustainable development, ecological, economic, political, and cultural sustainability [2]. EWB also indicates effective approaches including ensuring community participation, training the community, and optimizing the use of local resources among others [2]. While these suggestions offer great insight into engineering work in the developing world, they are relatively limited, specific to the work of EWB, and provide no context for evaluation.

EWB’s “dimensions” of sustainable development were also identified by L. David Brown, President of the Institute for Development Research and Professor of Organizational Behavior at Boston University [3]. Based on this model, Estes identified examples of sustainable and non-sustainable development as seen in Table 3-1 [4]. However, there is limited application to developing world projects.

Table 3-1 Selected Examples of Sustainable and Non-Sustainable Social Development Practices [4]

	Non-Sustainable Strategies	Sustainable Strategies
Economic	international systems governed by rules that work to the advantage of already rich countries and to the disadvantage of poor countries the existing concentration of 83% of the world's total income in the richest 20% of the population the persistence of widespread absolute poverty, especially within land-locked and resource poor developing countries	markets that fix prices for goods and services with reference to the human and environmental investments incurred in their production progressive "global" taxes based on wealth and consumption patterns the establishment of a global banking system that creates a common currency, maintains price and exchange-rate stability, channels global surpluses and deficits, and equalizes international access to credit (UNDP, 1992:78-79)
Political	war; state terrorism; oppression of historically disadvantaged populations centralization of power in the hands of self-serving elites the systematic exclusion of people from participation in the formulation and implementation of policies and laws that directly affect their well-being	popular participation in all aspects of governmental policy formulation and decision-making at all levels of social organization non-interference in the legitimate organizing activities of opposition political parties a significantly strengthened non-governmental sector, especially at the level of grass roots organizations and collectivities of people at local levels of political organization
Cultural	efforts to "homogenize" peoples and cultures with the goal of eliminating or minimizing cultural differences persistent socially-supported oppression of historically disadvantaged populations including women, religious and cultural minorities	the emergence of values, expectations and social mores that foster tolerance and moderation in accepting cultural differences of others gender role definitions that permit women and men to share equally in the making of decisions that affect them separately and together
Ecological/ Environmental	cash crop and other forms of agriculture that leave food exporting-countries vulnerable to hunger or malnutrition agricultural and other practices that depend on technologies and resources not available locally technologies that consume more energy than they generate approaches to short-term economic development that deplete non-renewable natural resources and pollute the environment	a stabilized world population the elimination of weapons of mass destruction developing and sharing appropriate technologies, especially those that reflect local needs, available natural resources and ecological realities protect and promoting biodiversity dependence on energy from ecologically renewable sources

More general models have been developed such as the one in by Fuchs and Mihelcic in Figure 3-1 [5]. Their model identifies the three core areas of sustainability and indicators in each area. This particular model is geared specifically toward engineering in the developing world.

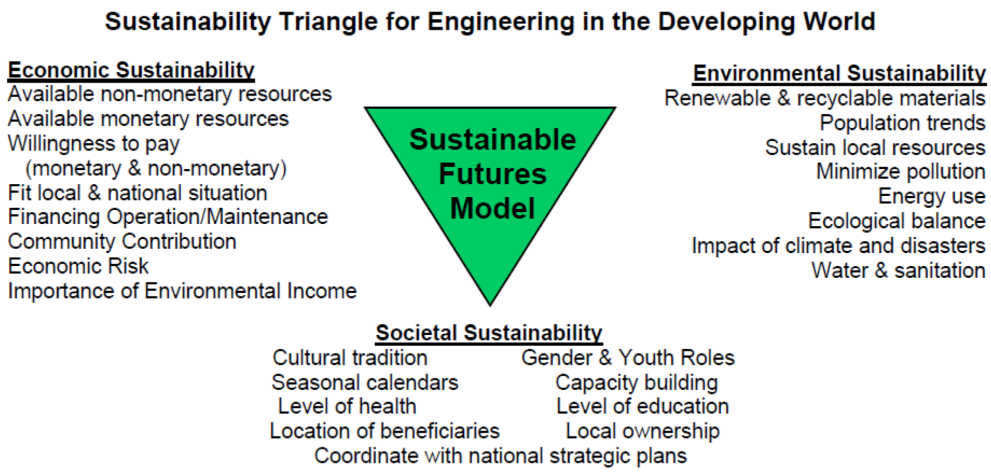


Figure 3-1 Sustainability Futures Model for International Development [5]

These models have identified key general concepts for sustainability, especially in engineering design. They provide guidelines to follow, but are still very suggestive. This work lacks an appropriate tool needed to qualitatively or quantitatively evaluate the sustainability of an engineering design project.

One such evaluation tool was developed in 2007 by McConville and Mihelcic [6]. Their metric adapts life-cycle thinking tools and focuses on international water and sanitation development. Their matrix can be seen in Figure 3-2 [6]. Accompanying this table is their criteria, which equates to four questions for each sector of the matrix. Answers receive a one or zero allowing for a quantitative evaluation.

Life stage	Sustainability factor: Sociocultural respect	Community participation	Political cohesion	Economic sustainability	Environmental sustainability	Total possible score
Needs assessment	1.1	1.2	1.3	1.4	1.5	20
Conceptual designs and feasibility	2.1	2.2	2.3	2.4	2.5	20
Design and action planning	3.1	3.2	3.3	3.4	3.5	20
Implementation	4.1	4.2	4.3	4.4	4.5	20
Operation and maintenance	5.1	5.2	5.3	5.4	5.5	20
Total possible score	20	20	20	20	20	100

Figure 3-2 Sustainability Assessment Matrix [6]

While this model finally allows a project to be assessed based on its sustainability, it can be cumbersome. The accompanying criteria are lengthy and can be a burden to use. Additionally, it may be difficult to use such a black and white grading system when answers may not be so straightforward. This metric was also designed for a specific type of project and is not necessarily transferrable. It would be beneficial to develop a more generic metric that can apply to any project and provide a more qualitative analysis. In the remainder of this chapter we create a new metric to fulfill this need.

3.2 Sustainability Standards

In developing our metric we identified two major standards that are beginning to pave the way for corporate sustainability, specifically on the social and environmental bottom lines. The first is the International Standard Organization's (ISO) standard 26000 for guidance on social responsibility [7]. The second is the Global Reporting Initiative's (GRI) "Sustainability Reporting Guidelines" [8]. These are both relatively new standards so their use is not yet widespread. However, they are considered two of the most reputable documents on the topic. These standards are discussed further in this section.

3.2.1 ISO 26000

ISO 26000 was created in 2010 by experts from 90 countries and 40 organizations involved in social responsibility [7]. They represented six stakeholder groups: consumers, government, industry, labor, non-governmental organizations, and a miscellaneous group of service, support research, academics, and others [7]. This group was balanced on a gender basis as well as on a developed and developing world nationality status [7]. The culmination of their work was then approved as a standard by the required 75% of the ISO member bodies [7].

The purpose of ISO 26000 is to "provide guidance on the underlying principles of social responsibility…and on ways to integrate socially responsible behavior into the organization" [7]. It pertains to all types and sizes of organizations as well as those at "various stages of understanding and integrating social responsibility" [7]. The standard covers six core subjects: human rights, labor practices, the environment, fair operating practices, consumer issues, and community involvement and development [7]. Within each core subject, a set of issues is described with related actions and expectations that provide assistance with integration and implementation. It is important to note that this standard is *not intended for certification purposes* [7]. Any claim or offer to be ISO 26000 certified would be a "misrepresentation of the intent and purpose" of the standard

[7]. It only serves to guide its users towards a maximum contribution to sustainable development [7].

3.2.2 Sustainability Reporting Guidelines

The “Sustainability Reporting Guidelines” were created by GRI a non-profit organization. Founded in 1997, GRI is network-based with over 600 organizational stakeholders and 30,000 individual supporters [8]. While headquartered in the Netherlands, it has regional offices in Australia, Brazil, China, India and the USA [8]. Additionally, GRI “enjoys strategic partnerships with the United Nations Environment Programme, the UN Global Compact, the Organisation for Economic Co-operation and Development, International Organization for Standardization and many others” [8].

The “Sustainability Reporting Guidelines”, created through these alliances and stakeholder engagement, provides a framework for corporations to report on the triple bottom line, introducing transparency and accountability [8]. The report consists of three disclosure areas: the strategy and profile of the organization, the management approach, and the performance indicators [9]. The core of the report that provides comparable information is the performance indicators. These are a set of specific topics organized in the following categories: economic, environmental, labor practices and decent work, human rights, society, and product responsibility [9]. The guidelines provide descriptions of each indicator along with information on how to report them.

Since GRI seeks to encourage the use of its guidelines, the final report receives a grade from GRI based on its level of reporting. A letter grade, A, B, or C, is assigned based on the quantity of information reported with A being an all-inclusive report [9]. A plus can be added to the grade by having the information externally assured [9]. Unfortunately, these grades are not a measure of sustainability, but rather of the commitment to reporting on sustainability indicators. An organization that receives an A+ may not be more sustainable than one that receives a C, but it is more transparent regarding its activities. This provides a way for stakeholders to better understand an organization's efforts to be more sustainable and a way for organizations to recognize flaws and make improvements.

3.3 Sustainability Indicators for Engineering in the Developing World

Although the roots of these standards are at the business level of organizations, a parallel can be drawn to engineering design projects. Instead of investigating all the aspects of a company, we seek to consider a single project. Using the triple bottom line as a framework and the ISO and GRI documents as sources, we created a set of sustainability questions. In this work we formulate these questions for engineering designers based on ideas and strategies often used by organizational managers. The questions are intended to be used by engineers to guide their design process and evaluate the final product for sustainability. The final set of questions can be seen in Table 3-2. The remainder of this chapter includes justification and descriptions of the questions organized by triple bottom line categories: financial, social, and environmental.

Table 3-2 Sustainability Questions

Financial	1	Rate reach people	How quickly can those in need be reached? Does the project plan for quick mass production or slower individual manufacturing?
	2	Profit management	If the project is intended to provide long-term financial stability, do the profits from initial sales and recurring profits from maintenance and repair allow for balanced income over time?
	3	Seasonal management	If this project targets a seasonal need, does it allow for year-round financial stability? Can income be generated all year, or is an alternative such as saving or a project for an opposite-season need necessary?
	4	Appropriate cost	Based on the purchasing power of the customer, can the final product be produced for a cost that allows for appropriate compensation of employees and profit, or is a subsidy or loan required to reduce cost?
	5	Local suppliers	Can the materials needed be purchased from local suppliers?
Social	1	Global need	How many people globally are in need of this project?
	2	Enabling	Is this an enabling project? Does the project provide opportunities for development or meet basic human needs?
	3	Culture conformity	Does the project conform to local customs, beliefs, or general perceptions?
	4	Community engagement	Does the project include local community engagement and steps for assessing needs for improvements?
	5	Local workforce	To what extent can the project provide for a business that utilizes a local workforce? Can manufacturing and/or repair be done locally?
	6	Education and training	Does the project provide an opportunity for learning new skills or honing old ones? Is training required or desired?
	7	Safety	Are there any safety concerns?
Environmental	1	Material efficiency	Does the project make efficient use of material resources?
	2	Recyclability	Can the project make use of recycled materials? Can materials be recycled or reused at the end of its lifetime?
	3	Energy efficiency	Does the project consume energy either directly or in manufacturing? Is the energy source efficient and appropriate?
	4	Water efficiency	Does the project efficiently use water resources?
	5	Waste control	What kinds of waste are produced by the project?

3.4 Financial

The following questions investigate the economic impacts of a project: the ability of the project to result in a financially sustainable business in the developing world. However, it also considers financial impacts on external constituents like suppliers and the ability to keep the flow of money in the local community. ISO 26000 provides some guidance in this area, but a great deal is interpreted through the use of basic accounting principles and financial statements.

F1. How quickly can those in need be reached? Does the project plan for quick mass production or slower individual manufacturing? ISO 26000 section 6.7.5 encourages sustainable consumption where patterns of production and consumption must be managed to ensure sustainability [7]. In order to achieve financial stability, it is very important to understand and balance how quickly a project is needed, how quickly it can reach those in need, and what pace is sustainable. Social entrepreneur Paul Polak states in his book “Out of Poverty” that if a project can’t reach at least one million people in the first five years, then it is not worth the effort [10]. Polak’s opinion seems idealistic, but it highlights the desperate need for quick assistance. Realistically, the rate of delivery should depend on the particular circumstances. Certain projects demand mass production in order to be inexpensive and come to market as quickly as possible, especially if designed to meet a desperate universal need. This may include projects for water devices that help provide clean water, a basic human need. On the other end of the spectrum, some needs must be met on an individual basis, therefore requiring customizable projects. This includes projects like prosthetics. Each individual in need requires a custom limb to fit their body. These types of projects typically require a more expensive and slower process. All methods along this spectrum can be made sustainable, but it is important to consider how meeting the need requires a strategically designed pace. This pace will impact the ultimate cost of the final product and the ability for a business to turn a profit. Therefore, the engineer must consider how design decisions can impact this pace and make appropriate choices.

F2. If the project is intended to provide long-term financial stability, do the profits from initial sales and recurring profits from maintenance and repair allow for balanced income over time? A business must be able to achieve financial stability to be sustainable and stay in operation. Unlike businesses in the developed world which can often handle larger market swings, it is likely that new and smaller developing world businesses need more consistent income to meet every day needs. This is something that can be inferred from typical financial statements, specifically the income statement. The income statement reports the revenue generated by a company. The bottom line on the statement represents the net losses or gains of the company over a given period. By looking at periodic income statements, one can determine whether income is consistent. The engineer can take a similar approach to that of the income statement by considering their project as its own business and considering the ways to generate income from that product. Generally, a large portion of the income is likely to come from the initial sale of the final product, but often more can be generated through maintenance and repair. There may be other ways of generating income such as add-ons. Overall, the engineer must consider how the costs associated can allow for balanced income for a business selling the final product.

F3. If this project targets a seasonal need, does it allow for year-round financial stability? Can income be generated all year, or is an alternative such as saving or a project for an opposite-season need necessary? A large number of final products are not used all year since they only meet seasonal needs. This would include equipment for farming or irrigation needed in the dry season. In "Out of Poverty" Paul Polak notes the importance of agricultural products, specifically for small, subsistence farm plots [10]. Products like these would only be used during the growing season. This would seem to prevent business and income generation during the rest of the year. However, it may be possible in the project to make appropriate business decisions to preclude or mitigate such a problem. For the engineer, it is important to consider how a design can be adjusted to accommodate the special circumstances surrounding a seasonal need and how this will impact possible business decisions.

F4. Based on the purchasing power of the customer, can the final product be produced for a cost that allows for appropriate compensation of employees and profit, or is a subsidy or loan required to reduce cost? It is important that all employees get paid a fair wage, comparable to what they could earn doing other work. GRI performance indicator EC1 investigates economic value generated in the form of employee compensation [9]. In addition, ISO 26000 section 6.4.4 suggests that organizations "provide decent conditions of work with regard to wages" and be in compliance with minimum wage laws and regulations [7]. The ability to compensate fairly can be inferred from the accounting on an income statement. The gross income comes from the sale of the products and services rendered at fair market prices affordable to the customer. All costs including production costs and wages are then subtracted off to obtain the net profit. If this number is positive, then the business is able to compensate employees and grow while selling a product for a reasonable price. If the net profit is negative, then the production costs are too high to grow the business or even allow for adequate compensation at appropriate price levels. This means subsidies or loans may be required to ensure fair compensation and growth. In order to be truly sustainable, the business should be capable of operating on its income alone. The engineer has a certain degree of control over the costs associated with manufacturing and must consider how this constrains the profitability of the business. A sustainable project will allow for as much flexibility as possible to ensure appropriate compensation and growth.

F5. Can the materials needed be purchased from local suppliers? Especially in the developing world, it is important for money to be reinvested in the local community. This helps ensure that the capital is spread among those who need it most rather than returning to the wealthy. GRI performance indicator EC6 explores "spending on locally-based suppliers at all significant locations of operation" [9]. ISO 26000 section 6.8.7 encourages organizations to "consider giving preference to local suppliers…and contributing to local supplier development where possible" [7]. The design of the final product has a great deal of impact on ability to use local suppliers. The engineer should consider material choices based on local availability and cost. An inexpensive desired material might not be available locally while a slightly more expensive alternative might be. Additionally, there might be differences in material cost based on sourcing location. In order to be ultimately sustainable, the engineer must be conscious of these options and seek to utilize local material suppliers if at all possible.

3.5 Social

S1. How many people globally are in need of this project? In order to assess the global social impact of the design, it is important to understand the level of need. Certain needs are concentrated to specific areas or people and may only lead to limited social reach by a product. Others may influence people throughout the world and will therefore have a much greater social impact. An engineer should simply recognize the distinction in order to better understand the social implications of the final product design.

S2. Is this an enabling project? Does the project provide opportunities for development or meet basic human needs? According to Maslow's hierarchy of needs, the bottom level to which people should be entitled is the set of basic human needs [11]. This includes such things as food, clean water, and shelter. Many people in the developing world are struggling to meet these needs. Therefore, addressing these needs should be the top priority. However, as these needs are met, a greater focus can be on development and rising up the hierarchy. According to ISO 26000 section 6.8.6, organizations should "consider contributing to the development of innovative technologies that can help solve social and environmental issues" [7]. Engineers should do the same. They should consider how their design projects enable people to solve a variety of issues and whether the technology delivered can lead to future development.

S3. Does the project conform to local customs, beliefs, or general perceptions? Respect for other cultures is a very important aspect of business. ISO 26000 section 6.8.4 states that culture is a "foundation for social and economic development and part of community identity" [7]. This section encourages recognition and promotes understanding and active support of cultural activities. Engineers should be conscious of the unique cultures that could impact design decisions and that their design decisions might impact culture. These decisions include major choices like materials and manufacturing processes, and minor choices like color, form, and other aesthetic qualities. Therefore the engineer should question whether any choice could oppose cultural norms and whether that opposition could cause a design to be rejected by the community. Projects that are accepted by the community by not countering local culture, are more likely to form a better business.

S4. Does the project include local community engagement and steps for assessing needs for improvements? ISO 26000 section 6.8.3 claims "community involvement…helps organizations to familiarize themselves with community needs and priorities" [7]. This helps ensure that the organization's efforts are compatible with the community. Most of all, it can help secure buy-in. GRI contains two performance indicators, SO1 and PR1 that discuss community engagement and product assessment [9]. SO1 investigates operations with "local community engagement, impact assessments, and development programs”. PR1 examines assessment specifically for health and safety. These ideas can also apply to a design project. The engineer should consider how the community can be involved in the design process. This can include everything from participating in initial brainstorming to creating designs to manufacturing prototypes. Additionally the engineer should consider how a project can continually be assessed by the local community. Collecting testing and assessment data from customers is an important method of guiding improvements.

S5. To what extent can the project provide for a business that utilizes a local workforce? Can manufacturing and/or repair be done locally? In order to achieve sustainability on the local level, a business should utilize local labor. According to ISO 26000 section 6.8.5, reducing poverty and promoting economic and social development can be partially achieved through job creation [7]. GRI performance indicator EC7 examines protocol for local hiring [9]. This urges a business to consider the effects of outsourcing. Outsourcing may be cheaper, but it can have negative effects on the business directly as well as on external organizations [7]. If development is the ultimate goal, keeping jobs in the local community is desirable. The engineer must therefore consider whether the design can be manufactured on a local level. This includes an understanding of the equipment available and skill set of the local workforce. ISO 26000 section 6.8.5 suggests that organizations “consider the impact of technology choice(s) on employment and, where economically viable in the longer term, select technologies that maximize employment opportunities” [7]. Additionally it recommends “participating in local and national skills development programs" which can improve the skills and abilities of the work force. This will tie in to the next question, but overall, the engineer should attempt to furnish a design based on these constraints.

S6. Does the project provide an opportunity for learning new skills or honing old ones? Is training required or desired? As noted above, utilizing a local workforce is an integral part of development. However, each locality may have workers with varying knowledge, skills, and abilities. Some workers may already be prepared while others may need training. GRI performance indicators LA10 and LA11 investigate yearly hours of training and employee support programs for skills management and lifelong learning [9]. ISO 26000 section 6.4.7 encourages organizations to "provide all workers at all stages of their work experience with access to skills development, training and apprenticeships, and opportunities for career advancement" [7]. Although the engineer is not necessarily responsible for creating such programs, they must consider how the requirements of the design will impact workers. If the design is too complicated and the skills can't be taught successfully, a local workforce is useless. The engineer must design for a balance where, if required aptitudes are not already available, they can be provided through training.

S7. Are there any safety concerns? Safety is the ultimate constraint on any design and applies to everyone from workers to end users. Laborers, especially in the developing world, need to be protected from unsafe practices, even if they are unfamiliar with risk. GRI contains a series of performance indicators dealing with safe labor practices, LA6-9 [9]. These explore workforce involvement in the monitoring and advising of health and safety programs, rates of safety concerns, and education, training, and agreements regarding health and safety. ISO 26000 sections 6.4.4 and 6.4.6 also contain a wealth of suggestions regarding physical, mental, and social working conditions and health and safety matters [7]. On the consumer side, ISO 26000 section 6.7.4 provides insight into ways to “provide products and services that, under normal and reasonably foreseeable conditions of use, are safe for users and other persons, their property, and the environment” [9]. While these may seem generally like business issues, the design itself can remove or mitigate many similar concerns. By reducing or removing any potentially dangerous activities from the manufacturing or repair of the final product, the engineer can improve safety for workers. Even if this is not possible, the engineer is at least aware of the potential danger and should advise on creating an appropriate safety program for the business. The engineer must also consider the intended end users and operation to design a safe product. If the product cannot be made inherently safe, then the engineer should plan for protective devices and safety information for users [7].

3.6 Environmental

E1. Does the project make efficient use of material resources? GRI performance indicator EN1 asks a company to investigate the total material used by weight or volume [9]. ISO 26000 section 6.5.4 contains an identical sentiment. This is particularly important in the design of any product, especially in the developing world. These parts of the world are typically already limited in their material resources and must therefore use them wisely. It is important for an engineer to examine all material use to determine if less can be used or if it can be used more effectively and efficiently to perhaps improve strength or product lifetime. Limiting scrap materials from manufacturing is also encouraged. An engineer can scrutinize the manufacturing process to determine where scraps are produced and make appropriate design changes to reduce waste. This correlates to the “reduce” portion of the 3Rs strategy.

E2. Can the project make use of recycled materials? Can materials be recycled or reused at the end of its lifetime? Recycling has become a key component of any environmental business strategy. GRI performance indicator EN2 asks a company to consider what percentage of input materials are from recycled sources [9]. ISO 26000 section 6.5.4 encourages the use of recycled materials [7]. The engineer should have an understanding of materials that can be recycled and lean toward the use of these materials in the product design. This encompasses the “recycle” component of the 3Rs strategy, but the question has been expanded to incorporate the “reuse” aspect as well. In conjunction with the previous question, the ability to reuse or recycle materials enables a more efficient use of new resources. An engineer should consider how unbroken parts can be reused in a new product without jeopardizing its integrity.

E3. Does the project consume energy either directly or in manufacturing? Is the energy source efficient and appropriate? Energy resources are typically just as limited as raw materials in most parts of the developing world. Therefore an engineer should analyze the amount of energy needed for manufacturing and for using the product as well as evaluate the potential sources of energy and the efficiency of those sources. This correlates to performance indicators EN3-5 of the GRI [9]. These look at direct and indirect energy consumption as well as efforts to save energy. ISO 26000 section 6.5.4 also recommends energy efficiency and the use of renewable energy sources wherever possible [7]. The engineer should ultimately create a project that uses the least amount of energy possible and utilizes the most efficient sources available. If this cannot be achieved, the engineer should help to procure additional, renewable, efficient sources to accommodate the greater energy demand.

E4. Does the project efficiently use water resources? In addition to materials and energy, water resources can also be quite scarce in the developing world. ISO 26000 section 6.5.4 and GRI performance indicators EN8-10 encourage a company to investigate all uses of water and the ability to recycle what is used for conservation purposes [7,9]. An engineer should consider how water is used in the manufacturing or use of a product and make efficient use of the resource. This includes limiting use to only necessary operations, recycling water until it must be discarded, and even providing methods for cleaning waste water for reuse.

E5. What kinds of waste are produced by the project? The GRI has a large number of questions regarding emissions and waste, performance indicators EN16-25 [9]. Additionally, ISO 26000 sections 6.5.3 and 6.5.5 include recommendations on pollution prevention climate change mitigation [7]. The question posed here refers to all kinds of waste which can include, but is not limited to, greenhouse gas emissions, scrap materials, and garbage. This is particularly important in the developing world due to a lack of education regarding the harm caused by some waste materials as well as the inability to adequately dispose of most waste. The engineer should therefore strongly consider all waste produced by the project and its adverse impacts. From there, the engineer should deliberate ways to reduce waste and develop a plan for safe disposal.

3.7 Conclusion

Using two reputable, international standards as a foundation, we were able to develop a set of sustainability questions for engineers. These provide appropriate breadth and depth to help engineers focus on the financial, social, and environmental bottom lines. They provide insight into the sustainability of engineering projects. Using them to evaluate existing projects exposes flaws that can be corrected in future ventures. Additionally, they provide an appropriate framework for guiding the design process for sustainability. In the next chapter this metric is used to evaluate several existing projects and in the following chapter it is used to guide a new design approach to bring inexpensive eyeglasses to the developing world.

3.8 References

[1] United Nations, 2007, “Indicators of sustainable development: guidelines and methodologies,” United Nations, New York.

[2] Engineers Without Borders - USA, 2005, “Community development guidelines”.

[3] Brown, L.D., 1991, “Bridging organizations and sustainable development,” IDR Reports, 8(4).

[4] Estes, R.J., 1993, “Toward sustainable development: from theory to praxis,” Social Development Issues, 15(3), pp. 1-29.

[5] Fuchs, V.J. and Mihelcic, J.R., 2007, “Engineering education for international sustainability: curriculum design under the sustainable futures model,” Proceedings of the ASEE North Midwest Sectional Conference.

[6] McConville, J.R., and Mihelcic, J.R., 2007, “Adapting life-cycle thinking tools to evaluate project sustainability in international water and sanitation development work,” Environmental Engineering Science, 24(7)

[7] International Organization for Standardization, 2010, "Guidance on social responsibility," ISO/Commission Electrotechnique Internationale, Geneva, Switzerland.

[8] “Global Reporting Initiative,” 2012, https://www.globalreporting.org/Pages/default.aspx.

[9] Global Reporting Initiative, 2011, “Sustainability reporting guidelines,”.

[10] Polak, P., 2008, "Out of poverty: what works when traditional approaches fail," Berrett-Koehler, San Francisco, Calif.

[11] McLeod, S., 2012, "Maslow Hierarchy of Needs," 2012, http://www.simplypsychology.org/maslow.html.

Chapter 4: Evaluation of Existing Projects

In this chapter we test the effectiveness of the metric in evaluate existing engineering projects for the developing world. All of the projects investigated have achieved some success and benefited people in some way. However, each relies on a particular model that works currently, but may be difficult to sustain in the long term. The goal here is to identify and explore the shortcomings and weaknesses of these projects. We investigate a range of projects from various organizations and for multiple purposes. The first four projects are the Leveraged Freedom Chair, the International Design Enterprise (IDE) treadle pump, the IDE drip irrigation system, and the One Laptop Per Child program. These provide insight into the general application of the sustainability questions. The final three are the AdSpecs, Focusspecs, and U-Specs. These are variations of eyeglasses designed specifically for the developing world and will be compared to our project specifically explored in the next chapter. A full analysis of all these projects can be found in Appendix A. Table 4-1 shows a color-coded matrix corresponding to the sustainability questions. Green represents questions that receive positive answers. Those that are yellow are questionable, and ones in red are problematic. In the rest of this chapter we discuss each project briefly and describe positive results and any significant issues in more detail.

Table 4-1 Color-Coded Sustainability Matrix for All Projects

			Leveraged Freedom Chair	IDE Treadle Pump	IDE Drip Irrigation	Laptop	Ad-Specs	Focusspecs	U-Specs
Financial	1	Rate reach people	Green	Green	Green	Green	Green	Green	Green
	2	Profit management	Yellow	Green	Yellow	Red	Red	Red	Red
	3	Seasonal management	Green	Green	Yellow	Green	Green	Green	Green
	4	Appropriate cost	Red	Yellow	Green	Red	Yellow	Green	Green
	5	Local suppliers	Yellow	Yellow	Red	Red	Red	Red	Red
Social	1	Global need	Yellow	Green	Green	Red	Green	Green	Green
	2	Enabling	Green	Green	Green	Green	Green	Green	Green
	3	Culture conformity	Green	Green	Green	Green	Green	Green	Green
	4	Community engagement	Green	Yellow	Yellow	Red	Red	Red	Red
	5	Local workforce	Yellow	Green	Red	Red	Red	Red	Red
	6	Education and training	Yellow	Green	Green	Red	Red	Red	Red
	7	Safety	Yellow	Yellow	Green	Green	Green	Green	Green
Environmental	1	Material efficiency	Green	Green	Green	Red	Yellow	Green	Green
	2	Recyclability	Green	Green	Green	Red	Yellow	Yellow	Yellow
	3	Energy efficiency	Green	Green	Green	Red	Green	Green	Green
	4	Water efficiency	Green	Green	Green	Green	Green	Green	Green
	5	Waste control	Green	Green	Green	Red	Green	Green	Green

4.1 General Projects

4.1.1 Leveraged Freedom Chair

Figure 4-1 Leveraged Freedom Chair [1]

The Leveraged Freedom Chair (LFC) is a wheelchair designed specifically for the disabled in the developing world and is seen in Figure 4-1 [1]. It is being designed by the Mobility Lab at the Massachusetts Institute of Technology and its partners and has been in development since 2008 [1]. Unlike a traditional wheelchair, the LFC uses the principle of mechanical advantage to enable users to navigate difficult terrain. It is constructed from bicycle components and materials available throughout the developing world. Trials of the LFC have been performed in East Africa and Guatemala and have resulted in valuable feedback and improvements.

Although the LFC is an enabling product that has gone through many design iterations, the matrix points out a few shortcomings in terms of sustainability. First is the global need for this product. Although there are many disabled people everywhere in the world, they are a minority and tend to be scattered. In general, one is not likely to find a large number of those in need at the local or regional level. This makes it very difficult to conceive a local business model that would allow for sustained production and repair. Therefore, although the wheelchair can enable its users, it is unable to provide any financial support. So despite the social improvement it provides, it may prove to be unsustainable on a financial basis.

Perhaps the most limiting factor is the cost of the wheelchair. The final cost including 30% overhead is approximately $200 [2]. Although this is considered to be a reasonable price between the typical $150-300 for standard wheelchairs, it is still not affordable for nearly anyone in the developing world [2]. This could likely equate to between one week and one month’s pay. In order to make the LFC less expensive, a subsidy or loan would be necessary. Subsidies are not sustainable, while loans can be. Micro-finance loans are becoming very common ways for people in the developing world to receive aid from those in the developed world. However, they still rely on the assistance of non-local entities. A sustainable loan would need to come from a local bank or loan agency within the region. Keeping the system local allows the entire community to benefit financially.

The final concern is the manufacturability of the wheelchair. Although the product was designed to be produced locally in the developing world, not all of the components can be made locally [1]. The core bicycle components are made and can be found in many developed locations throughout the world [2]. This makes it at least possible to find sources closer. However, this does increase costs. The remaining materials are likely found in the developing world, but their availability may limit potential manufacturing sites. Also, the processes and equipment needed to work with these materials may be limited to certain locations. For example, the welding machine necessary to join metal parts may not be as readily accessible. In order to ensure that the manufacturing process is sustainable, especially at the local level, an appropriate production and supply chain must be developed.

4.1.2 IDE Treadle Pump

Figure 4-2 IDE Treadle Pump [3]

International Development Enterprises (IDE) is an organization founded to address the need for small-scale farming technologies in the developing world [3]. One of their most successful products is a treadle pump seen in Figure 4-2. This product is a human-powered irrigation device [3]. It sits on top of a well and uses a stepping action on the treadles to pump water to the surface [3]. This product has resulted in other organizations beginning their own treadle pump initiatives leading to construction and testing in regions across the world.

This product also has sustainability weaknesses. The pump is priced between $20 and $100 depending on the type and location of purchase [3]. It is questionable whether this price includes overhead costs, but regardless, it is still expensive. This may be necessary to sustain profits and fairly compensate employees. This would be required for a sustainable business venture. Regardless, this price may be a significant burden on many potential customers in the developing world if they are required to purchase the product outright. A subsidy or loan would likely be necessary to make the pump affordable. However, this makes sustainability more difficult to achieve.

Additionally, it is questionable how this product can be manufactured locally. Although the materials may be available, the accuracy required during manufacturing and the processes needed appear more difficult to achieve. The piston-cylinder in particular seems like a complex system that requires a great deal of accuracy and precision. With the limited tools available, it is unlikely that this can be accomplished. The material forming and welding processes would need to be aided by additional tools. This can probably be done in a more centralized manufacturing location as opposed to locally.

This is sustainable, but could be improved by bringing more of the process to the local level.

4.1.3 IDE Drip Irrigation System

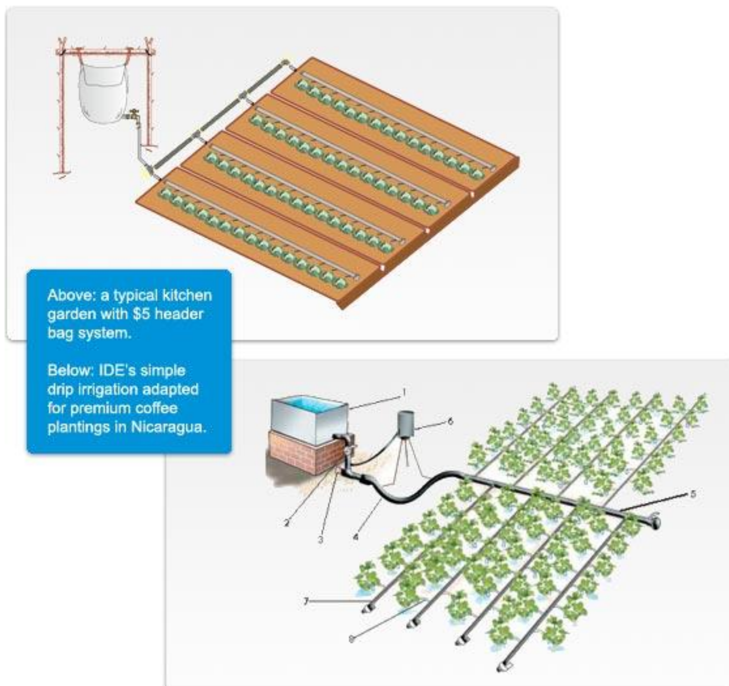


Figure 4-3 IDE Drip Irrigation System [4]

Another IDE product is its drip irrigation system seen in Figure 4-3. This farming product focuses on efficiency, especially in areas with scarce water resources [5]. The system utilizes a small water reservoir and multiple tubes with small holes. Using gravity, the water flows slowly through the small holes allowing plants to collect the water without much lost into the water table. This also allows for appropriate distribution of fertilizers. Most of all, these systems are modular and can applied to farm plots of various sizes [5]. This provides for a range of prices. A system for a small household plot would cost approximately $5.

Although this system can significantly improve irrigation effectiveness and result in increased farming output, it has its sustainability drawbacks for a business entrepreneur. It is questionable whether this product can provide financial sustainability. First, sales will likely depend on the season. This would make it difficult to balance the income from sales. Second, it is a very simple system. While this is good for the farmer, it is not necessarily beneficial to the business. It does not have parts that are likely to break or require repair, thus limiting recurring income generation. This will further limit the business' ability to balance its income over time. A diversified set of products and/or strong financial plan would be necessary to sustain a business selling drip irrigation systems.

The drip irrigation system also has manufacturing sustainability concerns. The materials are primarily plastics, not typically found in the developing world unless in finished form. It is also unlikely that the components needed for this system will be found in finished form. This means the bulk of the product must be manufactured in a location that can process plastic, not locally. This removes the need for a local workforce except for installation and minor repairs. In the long term, it is desirable to balance the labor better between the developed and developing worlds. A better supply chain and/or the means for manufacturing should be brought to the local or regional level in order to be sustainable.

4.1.4 One Laptop Per Child

Figure 4-4 XO Laptop from One Laptop Per Child [6]

The One Laptop Per Child (OLPC) program seeks to provide children in the developing world with "rugged, low-cost, low-power, connected" laptops seen in Figure 4-4 [6]. All of the hardware, software, and content were designed specifically for the learning environment in the developing world. This is intended to improve the education system by connecting these kids to each other and to the world [6]. This program has "seen two million previously marginalized children learn, achieve and begin to transform their communities" [6].

Despite a laptop's ability to enhance education, it may not be the best choice of tools. There are likely other alternatives that would be more sustainable for a variety of reasons. Primarily, the $200 price tag makes the laptop unaffordable to anyone in the developing world without significant financial assistance [6]. The laptop is currently being distributed on a donation basis and there is no evidence to show that a developing world business could ever be formed for sales and repair. The technology is simply too complex.

This complexity also means the laptop can’t be manufactured in the local communities in which it will be used. Not only are the materials unavailable, but the equipment and processes can’t be found either. This also means that a local workforce can’t be employed. Therefore, there is little provision for community buy-in and feedback.

Additionally, a laptop poses a much greater environmental hazard. In order to make it durable, it uses more material than would be necessary for a traditional laptop. Many of the materials used are also likely non-recyclable. Most of all, laptops can’t be disposed of easily due to hazardous components. Even in the developed world, computers can no longer be discarded to landfills. This is a threat to the developing world which often does not have appropriate means of handling any waste. For example, it would be a serious danger to leave used batteries in the environment to rot and potentially leak chemicals. Additionally, despite its reduced energy consumption, a laptop requires battery and electric power to operate. Electricity is not necessarily available in the developing world and the limited infrastructure that might be in place, may not be capable of handling a significant increase in its load. All of these environmental concerns make the laptop unsustainable.

4.2 Eyeglasses Projects

4.2.1 AdSpecs

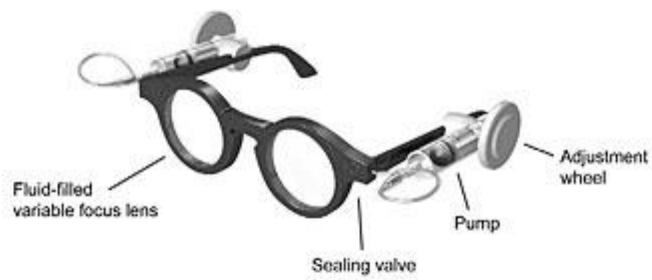


Figure 4-5 Ad-Specs Design [7]

Ad-Specs , seen in Figure 4-5, are adaptive eyeglasses invented by Oxford University professor Joshua Silver that are being manufactured and distributed through the Center for Vision in the Developing World [8]. AdSpecs are considered adaptive because they allow a patient to self-refract, or determine their own prescription need. This is done through the use of adjustable lenses. The particular form chosen for the AdSpecs is a fluid filled sac as seen in Figure 4-6 [8]. The user adjusts the amount of fluid in the sac to alter the prescription until they can see correctly. Currently, an estimated 30,000 pairs have been distributed throughout the developing world [9].

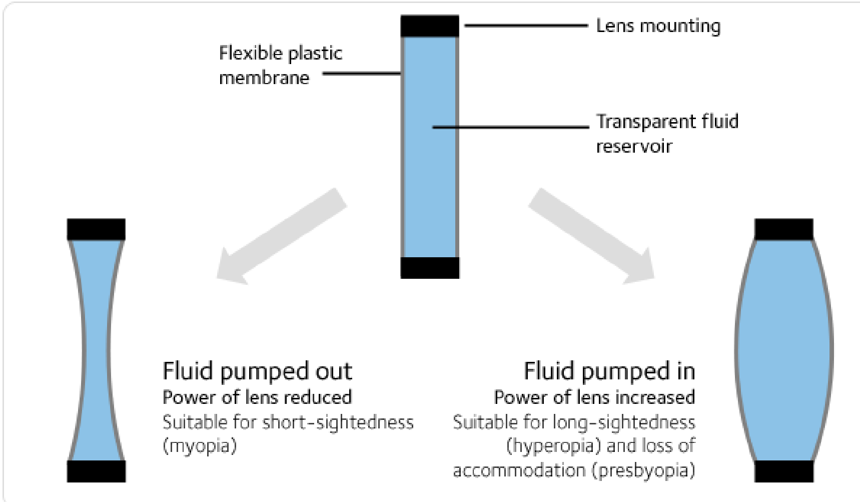


Figure 4-6 Fluid Filled Adjustable Lens Concept [8]

Although these eyeglasses were specifically designed for the developing world, there are numerous sustainability issues. Financially, they provide no benefit to the developing world and are realistically too expensive to be affordable to those in need. The AdSpecs are currently being distributed on a donation basis. They require the help of additional non-profit organizations on the ground to coordinate distribution and outreach [8]. A business model would need to be developed to use the eyeglasses to provide sustainable financial development. However, this is unlikely since only distribution occurs in the developing world.

This entire product is produced in the developed world in order to keep the cost low. The current cost of about $20 is already relatively expensive [9]. This would place a burden on the customer. The objective is to be able to produce these eyeglasses for $1 per pair, but there is currently no clear way to achieve this [9]. However, if these were to be made in the developing world, costs would conceivably be higher due to the lack of cheap and efficient mass manufacturing. This would make it less affordable to the customer and more difficult for a business to generate income and compensate employees. Additionally, this means that local suppliers forego the potential financial opportunities.

Since the eyeglasses are being manufactured in the developed world, this also limits social improvements. First, there is no need for a local workforce. Job creation is valuable for development, so it is not beneficial to have a product that can be sold but not manufactured in the developing world. This also means that workers are not able to develop and grow by learning new skills. Most importantly, there is low community buy-in due to limited methods of feedback and assessment. These eyeglasses are simply distributed without working with the community to develop and design an improved product. This led to an unattractive, one-size-fits-all product that is likely to be rejected for aesthetic reasons.

There are also potential environmental concerns. The plastic used in many of the components may be recyclable, but that is unconfirmed. Regardless, it is difficult to recycle plastic in the developing world. Also, the fluid lens technology results in wasted fluid that is likely discarded. It is unclear whether these eyeglasses can be recycled, but that would aid in making the design more sustainable.

4.2.2 Focusspec and U-Specs

Figure 4-7 Focusspec Design [10]

The Focusspec, seen in Figure 4-7, is another type of adaptive eyeglasses distributed through the Focus on Vision Foundation based in the Netherlands [10]. They are currently being distributed as part of the World Health Organization's Vision 2020 program [10]. Like the AdSpecs they allow the user to self-refract, but they utilize a different lens technology to make that possible. The Alvarez Lens is actually a pair of specially formed lenses that are able to shift with respect to one another to alter the prescription. This can be seen in Figure 4-8. This is actuated by a small dial on the side of the frame.

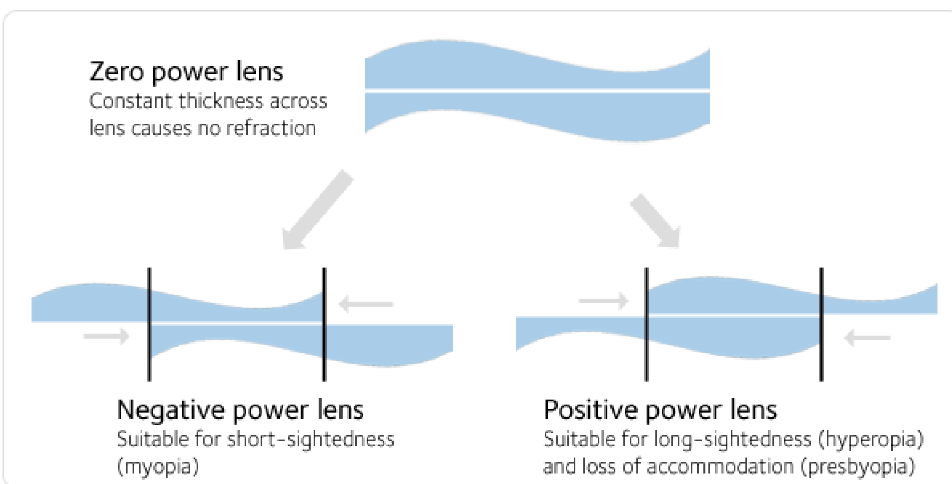


Figure 4-8 Alvarez Lens Principle [8]

The Focusspec also has similar sustainability concerns to the AdSpecs. Financially, they are also being distributed on a donation basis, which does not provide for the benefits of a business in the developing world. Also, since the Focusspec is also made from plastic and requires special lenses, it needs developed world manufacturing. However, this design is considerably less expensive to manufacture, so the increased costs that might be associated with transitioning to the developing world are reasonable. That is to say, the final cost to consumers would be more affordable and still provide room for profit and employee compensation. However, this product can currently only be distributed, not manufactured, and it is particularly difficult to envision a full business in the developing world.

This product also lacks the social impacts as a result of limited infrastructure in the developing world. Without manufacturing or business provisions, there is no need for a local workforce. This means no skills development and no jobs to provide additional income. There is also little feedback or assessment from customers to improve the design. These could all be provided by an appropriate business model.

Figure 4-9 U-Specs [11]

U-Specs, seen in Figure 4-9, were designed at the VU University Medical Center in Amsterdam and are nearly identical to the Focusspec [11]. They are also based on the

Alvarez lens concept and are intended for use in the developing world. In 2010, the UK-based NGO Adaptive Eyewear, producer of the AdSpecs, obtained the license to develop and manufacture U-Specs. Since the U-Specs are so similar to the Focusspec in design and are being manufactured and distributed in comparable ways, the set of shortcomings is basically identical.

4.3 Synthesis of Positive Results and Common Issues

4.3.1 Positive Results

Table 4-1 and the individual evaluations above allowed us to recognize several positive outcomes and key problem areas. As can be seen by the large number of green boxes in Table 4-1, these projects were able to accomplish sustainability in some areas. In general, most of the projects achieved high levels of environmental sustainability. This primarily stemmed from appropriate selection and use of natural resources. These projects generally made efficient and effective use of raw materials, energy, and water, with limited waste.

It is also noticeable that one project received no red boxes. The treadle pump project seemed to be generally the most sustainable and could provide a positive example for future projects. Socially, IDE’s method for developing the product includes community engagement. It was designed with developing communities to best meet their needs. In this case it can serve as a tool for irrigation and farming or provide water for drinking and cooking. This has led to an overwhelming acceptance of the product in many parts of the world. It was also designed to be the most consumer-friendly and reasonably priced by providing a range of pumps for the final product. It allows people of virtually any means to be able to purchase a pump. This customizability and affordability therefore makes the treadle pump highly conducive to business formation for sales and potentially repair providing opportunities for income generation.

The treadle pump was also designed to utilize a local materials, suppliers, and labor. The design uses an appropriate selection of natural, renewable, and locally available materials. These can be obtained from local suppliers, thus distributing some of the financial benefit. The skills and equipment required for manufacturing can also be found in the developing world with limited training. This creates additional jobs and means for increasing income. Overall, the treadle pump project provides a model that should be followed for sustainability.

4.3.2 Common Issues

While the positive aspects of the treadle pump should be emulated in future projects, the matrix unveiled numerous sustainability concerns to address. Questions F2, F5, S4, S5, S6, and E2 resulted in the worst responses for the majority of projects. The financial problems were the result of relatively expensive products that were being distributed by non-profit organizations. Without a business model, the local community is unable to benefit financially from these products. Additionally, since the majority of the products required production in the developed world, local materials can’t be used, cutting out local suppliers.

Socially, these products also provide little development assistance. These problems stem from the inability to manufacture these designs in the developing world. This limits the use of local labor, which is crucial to growth. Also, in order to develop, it is important for these people to learn new skills and be introduced to new manufacturing that may be useful for other purposes. Also, there is little community engagement, which results in products that are unappealing and unlikely to be accepted. This limits market penetration and puts a damper on the effort.

For the most part, these projects show appropriate environmental concern. However, there are still potential issues with material choices. Several of the products use materials that are less common in the developing world and are not recyclable. This is a problem with the general lack of appropriate disposal systems. The ability to reuse and recycle materials is extremely important for communities where resources are already scarce.

4.4 Conclusion

By investigating a variety of ventures we discovered six of the most common problems with developing world projects and made general recommendations to make them more sustainable. We also looked more specifically at various existing eyeglasses projects to determine flaws directly related to that particular endeavor. These flaws help in identifying a new approach to sustainably deliver inexpensive eyeglasses to the developing world. In the next chapter, we describe this new approach and its application to a new project.

4.5 References

[1] MIT Mobility Lab, "Leveraged freedom chair," 2011, http://mlab.mit.edu/lfc/Chair.html.

[2] Winter, A.G., et al, 2010, "The design, fabrication, and performance of the east african trial leveraged freedom chair," MIT Mobility Lab, Cambridge, Mass.

[3] International Design Enterprises, "Treadle pumps," 2012, http://www.ideorg.org/OurTechnologies/TreadlePump.aspx.

[4] International Design Enterprises – Canada, "Drip irrigation," 2012, http://www.ide-canada.org/OurTechnologies/DripIrrigation.

[5] International Design Enterprises, "Drip irrigation," 2012, http://www.ideorg.org/ourtechnologies/dripirrigation.aspx.

[6] "One laptop per child," 2012, http://one.laptop.org/.

[7] "Blogspot – World needs care," 2012, http://careofworld.blogspot.com/2010/06/adspecs.html.

[8] "Centre for vision in the developing world," 2011, http://www.vdwoxford.org/.

[9] Johnson, J., 2010, "How oil-filled lenses are bringing sight to those in need," 2012, http://gizmodo.com/5463368/how-oil+filled-lenses-are-bringing-sight-to-those-in-need.

[10] Focus on Vision Foundation, "An in variable power adjustable spectacle," 2012, http://www.focus-on-vision.org/focusspec_en.php.

[11] "Universal Spectacles," 2012, http://www.u-specs.org/?page=18054.

Chapter 5: Project for Sustainable Eye Care (ProSEC)

In this chapter we discuss our new project to deliver eyeglasses to the developing world, ProSEC. We cover the motivation for choosing this project, specifically referring to the weaknesses of previous attempts. We introduce the new approach taken with objectives and goals. This is followed by a description of the design process and the work performed in the developing world. Finally, the matrix is used to evaluate the project, pointing out how we improved overall sustainability.

5.1 Introduction

According to the World Health Organization, refractive error is the primary cause of low vision and the second greatest cause of preventable blindness [1]. There are an estimated one billion people in the world that have a refractive error and are in need of eyeglasses [1]. Many of these people are in the developing world and don't have access to eyeglasses.

Additionally, a major problem is access to optometrists. As was shown in Figure 1-2, in some parts of the developing world there is only one optometrist for one million people [2]. There is also a "lack of dedicated facilities and equipment" [1]. Without a trained professional equipped and available to diagnose one's refractive error, it becomes significantly more difficult to obtain appropriate eyeglasses.

To reduce the need for optometrists, previous attempts to deliver eyeglasses to the developing world relied on the use of adjustable lenses and self-refraction techniques.

This places the skill of the optometrist in the hands of the user. Through a simple lens adjustment, the user can tune the prescription of each lens to the desired prescription within the provided range. The user only needs to adjust the lens until they can see clearly.

Although these projects made use of ingenious technology, the previous chapter noted many flaws in their sustainability. These flaws primarily revolved around the need to manufacture in the developed world and the lack of financial support they provide to the developing world. ProSEC aims to address these problems through a vastly different approach and a new set of constraints.

5.2 Approach

The sustainability metric allowed us to identify flaws in other projects, thereby creating a set of constraints to be used in our current project. The ultimate goal of this project is to supply people in the developing world with the tools and training required to manufacture eyeglasses and distribute them to those in need. This should be done without the need for non-profit assistance, financial or otherwise. People should be able to form a business that makes money, employs local workers, and uses local suppliers. The final product must therefore be affordable and made from materials that can be found locally and manipulated with the limited equipment available.

As opposed to reinventing eyeglasses, ProSEC seeks to adapt the current processes and technology to fit the developing world. Manufacturing costs of cheap metal frames and plastic lenses are actually very low. The bulk of the expenses are incurred through the medical diagnosis and lens customization. This is where the most expensive equipment is used and corresponds to the processes that require the most skill and training. This project endeavors to redesign the equipment and the processes to reduce costs and enable those in the developing world to provide eyeglasses to those in need. Creating businesses that utilize the low cost and high availability of local labor will provide financial support and improve the standard of living in the developing world.

The engineering tasks for this project can be broken down into two main objectives: develop a way to shape customized lenses to fit frames and develop a way to diagnosis refractive error. This is coupled with management operations setting up supply chains and developing an appropriate business model. This chapter will focus on the engineering tasks.

5.3 Background Research

In order to best understand the process for cutting lenses and optometry, a partnership was formed in the developed world with an eye doctor and provider of eyeglasses. He provided an introduction to the equipment used, providing many samples for demonstrating the function of each unit. The following are descriptions of the tools used in the process and how they operate. The first four are used in preparing lenses for frames. They are used chronologically in the order shown to produce a finished lens. The next three are all diagnostic tools. These devices perform the same task in different ways, so they simply provide alternatives for the optometrist and patient based on personal preference.

5.3.1 Lensometer

Figure 5-1 Lensometer [3]

The lensometer (Figure 5-1) provides an accurate measurement of the prescription of a lens. A prescription is measured by the power of the lens required in a unit of diopters. A diopter is a number that is directly related to the difference in curvature between the two faces of the lens and is inversely related to the focal length of the lens. A zero diopter lens has identically curved faces and has an infinite focal length. A negative diopter lens is concave, and therefore causes light to diverge. A positive diopter lens is convex and causes light to converge.

To measure the prescription, a lens is placed between the eyepiece and measuring lens. The operator then focuses on sets of three parallel lines. When the lines come into focus, the diopter measurement can be read from the adjusting dial. This is used to determine one’s current prescription from a pair of eyeglasses or to verify the prescription of a lens to be cut.

5.3.2 Pattern Lens Edger

Figure 5-2 Horizon II Plastic Lens Edger [4]

The process of cutting a lens to the correct shape is known as edging and is done using the machine seen in Figure 5-2. This process takes a large stock circular lens and grinds it down to match a pattern for the chosen frame. After using the lensometer to verify the lens prescription, another machine is used to attach a small metal chuck with a piece of adhesive rubber, like double-sided tape. The lens is then placed on the lens mount on one end of a shaft and held in place with pneumatic pressure. The pattern is attached to the pattern mount at the other end of the shaft, mounted by three holes and also held in place with pneumatic pressure. The shaft connecting the lens and pattern is geared to a motor that rotates the lenses slowly. This entire subassembly is then actuated linearly by a second motor. This brings the pattern into contact with the pressure sensor while the lens contacts the grinding wheel. As the pattern rotates along the sensor, the assembly moves in and out, tracing the shape of the pattern on the lens side.

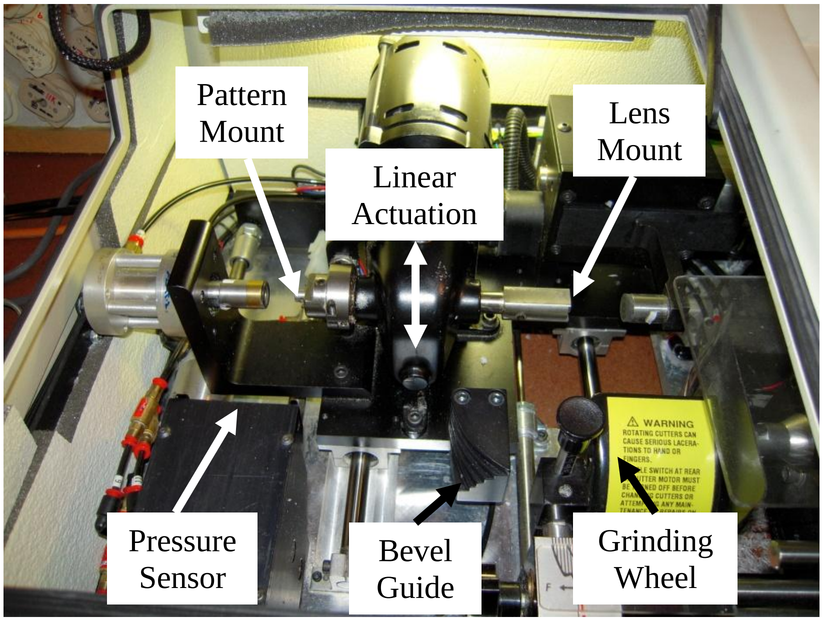


Figure 5-3 Components of Pattern Lens Edger

Once the shape is obtained, the edger produces a beveled edge. The cutting wheel has a special v-shaped section that is used along the edge of the lens. The bevel guide, a curved plate, is used to trace the proper location of the bevel along the edge of the lens. This produces a properly aligned, pointed surface that fits in the frame's groove.

5.3.3 Hand Lens Edger

Figure 5-4 Hand Lens Edger [5]

After the pattern edger performs the bulk cutting, the hand lens edger (Figure 5-4) is typically used to remove sharp edges and for small alterations. The grinding wheel is made of a very fine grit and therefore removes material slowly. It is appropriate for smoothing off the finished lens. This prepares the lens for installation into the frame.

5.3.4 Grooving Machine

Figure 5-5 Grooving Machine [6]

Many frames do not have metal completely surrounding the lens; they use a small plastic wire that is pulled tight and connected to the two metal ends. This design requires a groove to be cut in the edge of the lens as opposed to a bevel. The pattern lens edger cuts the lens down to shape, leaving a rimless edge. The grooving machine (Figure 5-5) holds the flat-edged lens and aligns it over a thin cutting disk. The lens rotates slowly as the disk cuts a groove around the entire edge.

5.3.5 Retinoscope

Figure 5-6 Retinoscope [7]

A retinoscope (Figure 5-6) is used by optometrists along with lenses of known prescription to diagnose refractive error. The device produces a streak of light which is shined in the patient's eye. The light can be seen on the back of the retina and based on the motion of the light, the optometrist can determine if someone is near- or far-sighted. The optometrist can then place a lens in front of the eye and repeat until the light becomes stationary, therefore determining the correct prescription. This is often verified by the use of an eye chart.

5.3.6 Phoropter

Figure 5-7 Phoropter [8]

A phoropter (Figure 5-7) is often used after initial refractive error diagnosis to more accurately determine the proper prescription. This device contains all the components of a lens kit in a compact form. This allows the doctor to quickly and easily switch between lens prescriptions while the patient continues to look through the same hole at an eye chart.

5.3.7 Focometer

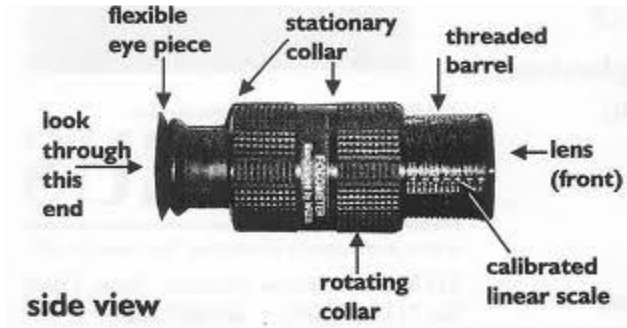


Figure 5-8 Focometer [9]

A focometer (Figure 5-8) is a non-standard tool that can perform the same diagnostic function. It utilizes two lenses, one stationary and one moving, to adjust focus. The distance between the lenses coordinates to a prescription and is calibrated so one can simply read a measurement when an object is in focus. Similar technology is also used in binoculars.

5.4 Lens Edger Design

It was determined that one of the most crucial and expensive piece of equipment necessary for preparing lenses was the pattern lens edger. This machine performed the majority of the work and was responsible for the accuracy and precision required to make a lens fit a frame. Therefore, this machine became the focus of the initial design project. The design was guided by the sustainability metric but also by mechanical design principles. The process also included several visits to the developing world to gather information, evaluate a design, and build a prototype. This section will cover a basic discussion of the principles used, a description of the final design and prototype, and a summary of the work done in the developing world.

5.4.1 Principles

A set of design principles were used along with the sustainability questions to help guide the process. These principles come from the book "Elements of Mechanical Design" by James Skakoon [10]. They are considered universal and apply to all forms of mechanical design. The three principles that were stressed most for this project were simplicity, load paths, and prototyping. A full discussion of these principles can be found in Appendix B, but the following is a brief explanation of each.

In terms of simplicity, Skakoon says to "create designs that are explicitly simple – keep complexity intrinsic" [10]. "The less thought and knowledge a device requires, the simpler it is" [10]. Load paths define the flow of internal forces or moments through a part and joints as if the load were a fluid. This helps in determining critical points where failure may be likely. Skakoon provides several desirable goals for load paths: equal distribution of flow lines throughout, shortest and most direct load path, minimize the number of times flow lines converge and diverge, avoid concentrations, use gentle rather than abrupt changes in direction, and avoid bunching around corners [10]. This provides a cheap and simple alternative to finite element analyses.

Prototypes are useful because "there is no substitute for a real, physical model" [10]. Skakoon claims that at the most simple level prototypes simulate function, size or form, and process [10]. Functional prototypes can help determine if a concept is viable. Sizing and forming prototypes give information on look, feel, weight, etc. Process prototypes assist in evaluating the manufacturing process. Prototypes can represent any one of these or any combination. The more that is included, the closer it is to the actual final product. However, one must always consider the exact purpose for which a prototype is made so that it can be analyzed and broken down appropriately.

5.4.2 Developing World Research

Additionally, a better understanding of conditions in the developing world is very important to produce an appropriate design. It was important to know about the culture and people as well as the kind of work that can be done at a local level. In order to gain this perspective, an initial trip was taken to San Pedro La Laguna, Guatemala, a village on Lake Atitlan approximately three hours from the capital, Guatemala City.

The goal of this trip was to gather as much useful information as possible. This began with determining the prevalence of eye care and eyeglasses in the region, in order to determine the level of need for question S1. It was discovered that one could obtain eyeglasses for reading at the local market. However, eyeglasses for the more common nearsightedness could only be obtained in cities multiple hours away. This was primarily due to the fact that the only optometrists available to prescribe eyeglasses were found in these cities. After visits to two elementary schools and walking through several villages, it was determined that approximately ten percent of people interviewed were in need of some sort of corrective vision. However, we noticed that very few people wore eyeglasses. A child wearing eyeglasses explained that his were obtained at a university in the city but were paid for by an American family. An older, wealthier gentleman traveled to Guatemala City to obtain his eyeglasses, which cost him the equivalent of about $300.

He explained that this was very uncommon and that most could not afford such a luxury. Overall, it was discovered that access to eye care and eyeglasses was basically non-existent in this region due to cost and availability. Therefore our design would need to pay particular attention to questions F1 and F4.

We also gathered information with regard to manufacturing ability and available materials. Several shops were found selling stock materials as well as various kinds of hardware. Nearly all of the material was steel. This also correlates to the equipment and processes being used by local workers. A couple of welding shops were found making chairs and fences. There were also several automobile repair shops, primarily for motorcycles, the most common form or transportation aside from the small three-wheeled taxi carts. Through a series of connections, we found the most extensive shop in the region. It was primarily equipped for woodworking and motorcycle repair, but contained several large metalworking tools from a grinder to a welder. However, most of the other tools were smaller power and hand tools including a drill, hacksaws, pliers, and screwdrivers. This meant that equipment and processes would certainly be limited, thus affecting questions S5 and S6.

We also observed the workers in these shops. They often had a decent understanding of how to use all of the equipment but were not always careful when it came to safety. For example, only one welder used eye protection. There was also a lack of welding jackets or gloves. In general there was limited use of safety glasses for even simple processes, despite the inherent dangers. This could likely be attributed to a lack of these safety items but can't be considered acceptable by an engineer. Due to the impact on answers to questions S5, S6, and S7, these concerns would certainly be considered in the new design.

The most interesting piece of information gathered was the western influence in the region. Despite being such an impoverished area, there was a distinct stylistic influence from the western, developed world. Although the women wore mostly traditional garb, the men donned blue jeans and button-down shirts. Even the children dressed like American kids in t-shirts and pants. The school uniforms for children in one village comprised a polo shirt and khaki pants. This western influence was confirmed by speaking with many of the villagers. This meant stylish eyeglasses would be a requirement if the people were actually going to wear them. In terms of the design, these concerns would be reflected in the answers to questions S3 and S4.

5.4.3 Initial Design

The first task was to develop a new design for the pattern lens edger. This would be done in the developed world and then prototypes would be made, first in the developed world and then plans would be given to people in the developing world who could then try to build an identical model. Therefore, it was designed and built under constraints for Guatemala. This meant using materials and equipment that were found locally or those that could easily be imported from surrounding areas, in accordance with questions F5 and S5.

The pattern lens edger was so heavily constrained that it seemed impossible to reproduce. However, the grooving machine operated similarly and had far fewer constraints. It was decided that the new design would look more like the grooving machine in form. Certain functions would need to be added, included the ability to trace a pattern and bevel the edge.

Overall, based on Skakoon’s principles, the entire machine needed to be simplified. This meant investigating each component and subassembly, replacing more complex parts with simpler alternatives, and limiting the total number of required pieces. Also, to maintain structural integrity under the applied forces, load paths were considered. This ensured appropriate strength was available in load-bearing components. Finally, the design was prototyped on two occasions to test the viability and manufacturability of the design.

The initial design and prototype can be seen in Figure 5-9 and drawings can be seen in Appendix C. The grinding function is performed by a sandpaper wheel attached to a small motor, similar in form to a Dremel tool. This is mounted to one of two parallel plates. The grinding wheel is identical in size to a tracing wheel fixed to the second parallel plate. These plates are aligned with a small fixture and welded to the base plate. The hinged lens-holding mechanism also connects to these plates through a simple axle. The six vertical bars that make up the holder are identical. They are held together by an aligning fixture in order to have the connecting bar welded across each. These bars contain clearance holes for the shafts that hold the lens and pattern. The mechanism for holding includes several round chucks attached to each side of the lens and pattern and springs to ensure a tight grasp. The shaft coupling the lens and pattern also contains a turning wheel for assisting in manual rotation.

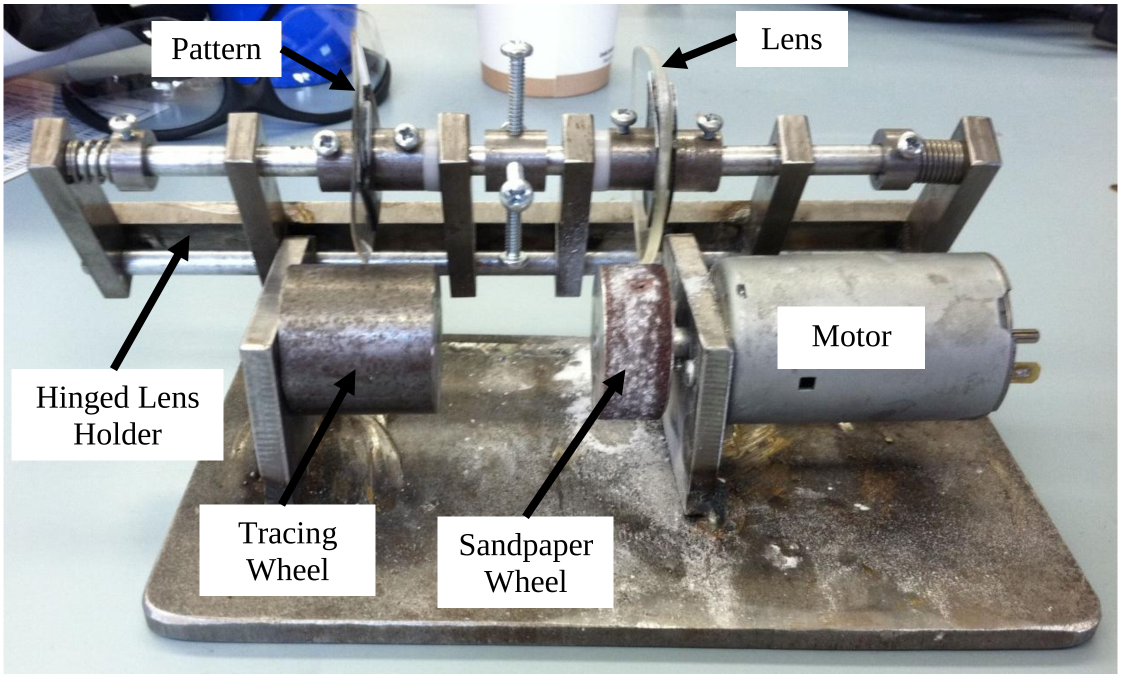


Figure 5-9 Initial Pattern Lens Edger Prototype

Overall, this design simplified the edging machine down to a cost of under $50. Only one motor was used, thus relying more on manual work. An expensive cutting wheel was turned into a replaceable sandpaper grinding wheel. Sensing was done mechanically. Shortcuts were taken to remove the need for many precise components like bearings, bushings, and precision shafts. Welding was used instead of hardware where possible due to a general lack of fasteners. Additionally, only a few stock materials were used for all of the components. This made manufacturing simpler and required less investment costs.

Load paths were also strongly considered in the design of the lens holder. The six vertical bars, although cantilevered, were made from thick steel to prevent bending. The length of the bars was also limited to what would be needed to accommodate a relatively large lens. Also, the distance between bars was minimized to shorten the load paths. This limited stress in the final product and resulted in few concerns about the failure of components.

Finally, prototyping was particularly valuable in evaluating the design and determining flaws. The initial prototype exposed accuracy issues in the cut lenses due to the simplifications that were made and potential problems in manufacturing. However, it was still important to produce a prototype in the developing world to better understand the reduced manufacturing abilities and redesign more appropriately. The next section covers the first prototyping effort in Guatemala.

5.4.4 Prototyping and Redesign in the Developing World

A second trip was taken to Guatemala to make an attempt to reproduce the initial prototype in accordance with question S5. Several weeks prior to leaving, drawings of components and pictures were compiled and sent to our partner in the area. They were asked to make an attempt to produce the design on their own before we arrived to assist. This turned out to be very unsuccessful. Several pieces were cut and prepared upon our arrival, but most had many issues. Dimensions were not very accurate due to a lack of precision equipment. Holes were too large or too small because of differences in available drill bits. Also, stock materials were slightly different sizes, which were not accounted for in the design. This made the parts useless, but what we learned was priceless. We discovered that we were only communicating the form of the design and not the function. Instead of trying to recreate our design based on the intended function, our partner was only attempting to copy our design. Therefore, when identical tools and materials couldn’t be found, the design could not be recreated successfully.

In an effort to make efficient use of the trip and the availability of several workers including an engineer, a new design was brainstormed and created. This enabled us to better adhere to question S4 and take advantage of the workers knowledge and creativity. The prototype can be seen in Figure 5-10. It is almost entirely made from materials found locally. The motor and grinding wheel are the exceptions. These components also did not change between designs. The lens holder assembly is where the majority of problems occurred, so that became the focus of the redesign.

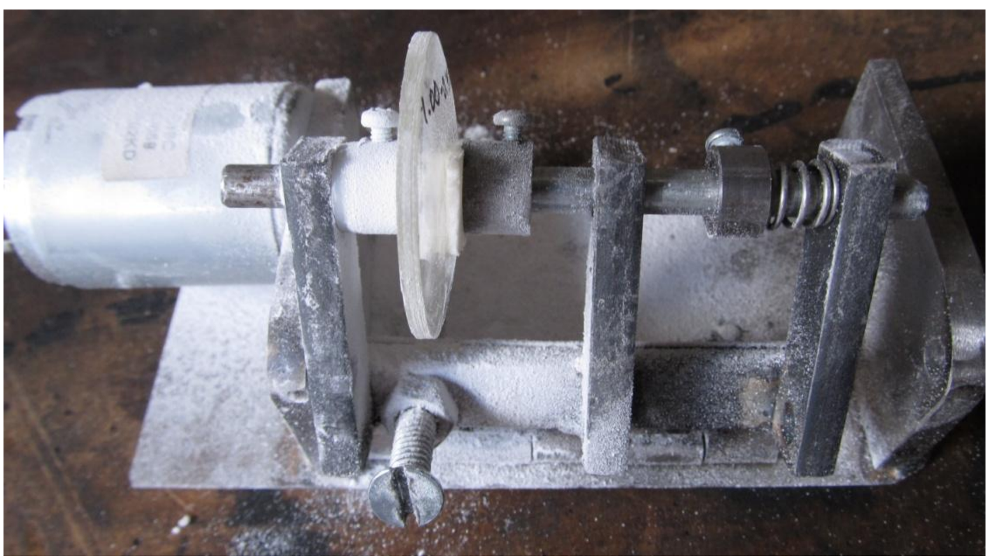


Figure 5-10 Final Lens Edger Prototype

The biggest difference in this design is the simplification of cutting only round lenses. In order to make it easier to cut, it was determined that a uniform radius would be ideal. The new design utilizes a simple door hinge to provide constraint. It was modified by adding a thin wire to the pin to reduce slop. This resulted in more friction, but was manageable. Three bars were then drilled with a drill press to provide aligned holes. With a fixture, the bars were aligned properly along the hinge and welded in place. Another hole was drilled in the hinge and a nut was welded over it. This provided a set screw that can be adjusted to cut bigger or smaller lenses. Finally, the other half of the hinge was welded to the base plate.

This design was then tested several times. The goal was to cut multiple lenses to the same size without adjusting the machine. In the end this precision was accomplished. Several lenses were cut and were found to be within 0.005" on the diameter. Additionally, the circular shape was found to be plus or minus the same amount on the diameter all the way around each lens. Although the lens was circular, it was a step in the right direction as far as producing a simple yet precise machine.

5.5 Diagnostic Tool Design

Although the equipment for cutting lenses and preparing eyeglasses is much more expensive, it is still vitally important to be able to diagnose refractive error correctly. The equipment to do so either requires a great deal of skill and/or money. Therefore, it was also important to design a more appropriate diagnostic tool that is cheap and simple, and can be used with little training. This work was done by a group of mechanical engineering senior design students in 2011-2012.

After learning several practices for diagnosing refractive error and investigating the equipment used, it was determined that the focometer provided the least complicated method. Therefore, a design was created around the concept of using two lenses with an adjustable, calibrated spacing. The final design and prototype, as seen in Figure 5-11, is very simple and is estimated to cost about $20 in the US. This design utilizes two PVC tubes with caps that fit within one another. The stationary lens fits in the cap at the end of the outer tube and is placed up to the eye of the patient. The inner tube containing the moving lens is extended from the outer tube by hand until an object comes into focus. The shaft of the tube is then calibrated with markings denoting the refractive error.

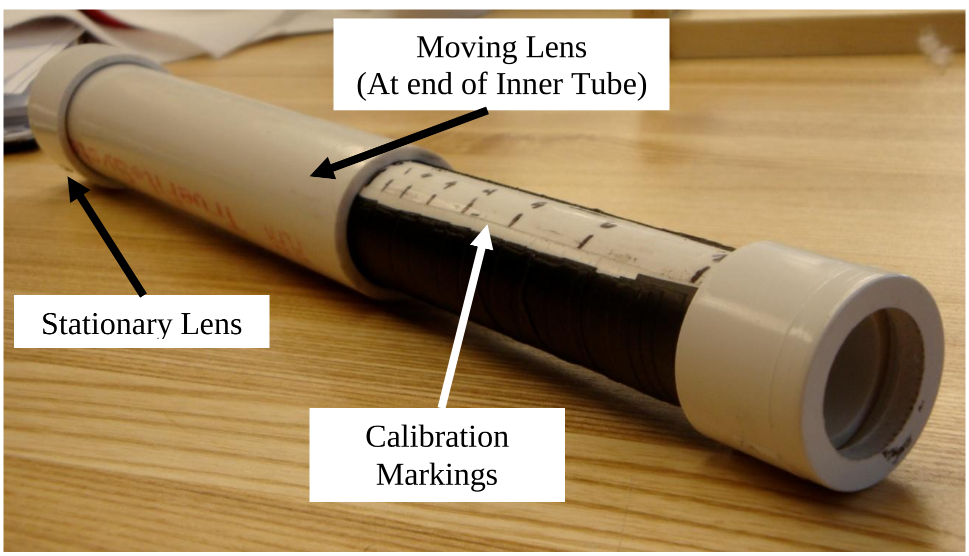


Figure 5-11 Diagnostic Tool Prototype

Based on an optical analysis using ray diagrams and appropriate formulas, it was determined that a device of reasonable size would require a -12 diopter stationary lens and a +4 diopter moving lens. Since a -12 diopter lens would be more expensive, two -6 diopter lenses were combined utilizing the additive property of lenses placed back to back. Additionally, calculations with this lens combination allowed for calibrated markings to be added. These markings are quite close together in the positive range, but are much further apart in the more common negative range. This allows the device to be more accurate in the more common and more desired range of use.

Initial tests have found the device to be relatively accurate, to at least within one diopter of the users medically identified refractive error. However, it has not been extensively tested either in the developed or developing world. Additionally, although the design was intended to be manufactured in the developing world, it has not yet been tried.

5.6 Project Evaluation via Sustainability Matrix

Although neither tool can be considered in completed form, the prototypes have served their purpose as proofs of concept. These designs both convey that it is feasible to consider a cheap and simplified redesign of lens edging and optometry equipment to suit the developing world. This means that redesigning traditional eyeglasses is not necessary and also likely less sustainable than our approach. Table 5-1 shows a color-coded sustainability matrix for the various eyeglasses projects investigated. The remainder of this section will describe the changes that have led to more positive evaluations for the new project on particular questions.

Table 5-1 Color-Coded Sustainability Matrix for Eyeglasses Projects

			Ad-Specs	Focusspecs	U-Specs	ProSEC
Financial	1	Rate reach people	[green]	[green]	[green]	[green]
	2	Profit management	[red]	[red]	[red]	[yellow]
	3	Seasonal management	[green]	[green]	[green]	[green]
	4	Appropriate cost	[yellow]	[green]	[green]	[green]
	5	Local suppliers	[red]	[red]	[red]	[yellow]
Social	1	Global need	[green]	[green]	[green]	[green]
	2	Enabling	[green]	[green]	[green]	[green]
	3	Culture conformity	[green]	[green]	[green]	[green]
	4	Community engagement	[red]	[red]	[red]	[green]
	5	Local workforce	[red]	[red]	[red]	[yellow]
	6	Education and training	[red]	[red]	[red]	[green]
	7	Safety	[green]	[green]	[green]	[green]
Environmental	1	Material efficiency	[yellow]	[green]	[green]	[green]
	2	Recyclability	[yellow]	[yellow]	[yellow]	[green]
	3	Energy efficiency	[green]	[green]	[green]	[green]
	4	Water efficiency	[green]	[green]	[green]	[green]
	5	Waste control	[green]	[green]	[green]	[green]

5.6.1 Financial

ProSEC makes several drastic changes that will improve overall financial sustainability. The most obvious change is the lack of reliance on non-profit organizations for distribution. This project intends to empower people in the developing world by creating a business model for selling eyeglasses, similar to the developed world. This includes training people to serve as optometrists. Using a redesigned diagnostic tool they can give accurate eye exams and ensure that people are receiving the correct prescription. This also includes providing jobs in edging lenses. It also may be possible in the future to bring additional aspects of manufacturing such as lens and frame production to at least the regional level. By creating jobs and forming perhaps a chain of businesses, people in the developing world may be able to increase their income and provide longer term financial stability.

By creating businesses, it is also likely that money will be reinvested in the community by using local suppliers. Since some stages of production may be more difficult to accommodate in the developing world, it is unclear how much this venture can benefit local suppliers. However, by intending to do as much manufacturing as possible in the developing world, there is certainly an effort to continually assist the local community financially, including suppliers.

5.6.2 Social

This approach also cleared up several social issues. One of the less obvious is the notion of designing with community engagement and feedback. A great deal was accomplished by spending time in the developing world talking to and working with the people. This allowed us to discover the influence of western culture and understand the reluctance to accept anything not deemed stylish by even our standards. This is particularly important for eyeglasses since they are a fashion item. So despite the effectiveness of the AdSpecs and other project designs in correcting vision, their unattractiveness could prove ineffective. ProSEC was developed specially to use any eyeglasses deemed attractive by the customer.

Working with the people also gave us an opportunity to take advantage of their ingenuity. Many of the workers, especially the auto mechanics, were quite skilled and had excellent problem solving skills. Their ability to take even broken machines apart and return them to working order could prove useful in brainstorming creative solutions for designs. By taking this approach we were able to include them in the process, which will hopefully provide a better result.

The majority of the social impact revolves around the manufacturing focus in the developing world. As described in the financial section, the hope is to create a business with as much manufacturing as possible in the developing world. This is an effort to create jobs for the local community. Currently, only some of the production can be done in the developing world, which at least means some need for local labor. There is a need for “diagnosticians” and lens preparers, which is certainly the bulk of the labor. However, this approach seeks to continually bring production to the local level, therefore increasing the number of local jobs over time.

Providing jobs also means providing training. While this work will hopefully improve skills and abilities that the laborers already have, it will also provide an opportunity to learn new skills. The optometry aspect in particular is something that will be very new to these people. Training even a few people in diagnosing refractive error will lead to a greater knowledge of the problem and perhaps reach a larger audience. There is also the potential for training on the use of the equipment to cut lenses to lead workers to see additional uses or new possibilities. In general it is this furthering and continuing education that will hopefully spark creativity and aid in development.

5.6.3 Environmental

From an environmental aspect, this approach seeks to have as little impact on nature as possible. The focus is on efficient and appropriate use of material and potential recycling and reuse. A lot of this already takes place in the developing world where resources are so scarce and things must be reused all the time. By bringing manufacturing to the developing world, it is important to consider using as little material as possible and using material that is readily available. This can even be recycled material and if possible, whole parts can be reused to reduce the need for raw material.

More important is the concern for components manufactured in the developed world. Initially for this project, stock lenses and frames are likely going to be supplied to the developing world. The lenses will be made of plastic and even if they are recyclable, there will be no venue for doing so in the developing world. However, it may be possible to encourage reuse of lenses that are in good condition. They can either be inserted into similar frames or cut again depending on size restrictions. Frames on the other hand are likely not recyclable. Therefore it may be wise to consider the possible reuse of frames. This will require that they be of sturdier construction. Overall, this approach is considering these possibilities based on the need for environmental sustainability.

5.7 References

[1] “Centre for vision in the developing world,” 2011, http://www.vdwoxford.org/.

[2] Shakesville, “Shaker thumbs" 2011, http://shakespearessister.blogspot.com/2009/09/shaker-thumbs_25.html.

[3] Ophthalmic Instruments, Inc., “Marco 201 lensometer,” 2012, http://ns2.internetsimplicity.net/product.php?productid=405.

[4] Lab Talk Online, “Horizon II plastic bevel edger,” 2012, http://www.labtalkonline.com/Product_detail.asp?ProdID=1141.

[5] Aoshen Lens, “Hand lens edger mod.CCP-7,” 2012, http://www.sunshineopticos.com/cp_ck.asp?id=118.

[6] Aoshen Lens, “Lens grooving machine mod.CCP-3,” 2012, http://www.sunshineopticos.com/cp_ck.asp?id=115.

[7] Sight Reach Surgical, “Welch allyn streak retinoscope,” 2012, http://www.iefusa.org/Catalog/SRS_FRONT/ProdDetail.php?product_id=50&s_category_id=22&=3.

[8] The VisionHelp Blog, “Amblyopia and higher order aberrations » phoropter-topcon-vt-10,” 2012, http://visionhelp.wordpress.com/2011/05/24/amblyopia-and-higher-order-aberrations/phoropter-topcon-vt-10/.

[9] InFocus, “Focometer fact sheet,” 2012, http://www.infocusonline.org/focometerfactsheet.html.

[10] Skakoon, J.G., 2008, "The elements of mechanical design," ASME Press, New York.

Chapter 6: Conclusions and Future Work

This chapter provides closure on sustainability, the use of the sustainability questions, and the potential impact of the new eyeglasses project. It will discuss the importance of sustainable design and the benefits of using the sustainability questions. It will reinforce the intended uses of the sustainability questions and the matrix form. Most of all it will emphasize ProSEC and the great promise of its innovative approach. Finally, this chapter will provide suggestions for future work on ProSEC and on the sustainability questions.

6.1 Sustainability

As was discussed throughout this thesis, sustainability means a great deal more than just protecting the environment. As the triple bottom line concept emphasizes, it means sustaining something for a long time financially, socially, and environmentally. This thesis investigated the importance of sustainability in the developing world as steps are made toward advancement. Limited engineering efforts are being provided to make this possible while much of the present work is unsustainable. The strong reliance on non-profit support and the continual influx of donations presents no long-term financial solution. These efforts supply few jobs and other opportunities for social development. Additionally, proper waste disposal and recycling are virtually non-existent in most of the developing world. Yet there are still few attempts to use and manage local and environmentally friendly resources. In order to address these concerns, we created the sustainability metric. We believed that answering the questions in the metric could help ensure sustainability in future engineering work for the developing world.

6.2 Metric for Sustainability

While general design principles often provide adequate guidance to engineers, additional assistance needs to be provided for sustainability. Currently, the majority of sustainability concepts are applied to the business work of organizations and corporations and very few can be used to assist in engineering design. However, sustainability is just as important if not more important in engineering, especially for developing world projects. To fill in this "hole" in the typical engineering design methodology, we created a sustainability metric. This was manifested in the form of open-ended engineering questions in the triple bottom line categories of finance, society, and environment. The questions were induced from common financial protocols and two internationally recognized standards on sustainability. Although these were geared toward the work of corporations, parallels were drawn to engineering design projects. These questions were successfully used for two functions, evaluating and comparing previous projects and guiding future projects.

6.2.1 Evaluation and Comparison

To test the ability of the questions to unveil sustainability flaws, several developing world projects were investigated. The questions were answered based solely on the final products and revealed areas of concern for each individual project. These were color-coded to identify the significance of the problem. This was helpful when the answers were put into a matrix form to allow for comparisons across projects. It allowed us to determine more universal concerns. In order for projects to become more sustainable they must focus on providing financial support and utilizing local resources, specifically materials and labor. These projects should enable the formation of businesses to provide increased income. They should also use familiar materials provided by local suppliers and employ the local labor force. These were the primary criteria that led to poor evaluations and supplied insight for guiding future projects.

6.2.2 Guidance

The ability to use the sustainability questions in a matrix form was particularly useful for comparing previous eyeglasses projects to benchmark and determine a new approach. The questions were answered for three separate projects to develop and distribute eyeglasses in the developing world. The matrix was color-coded and allowed us to identify the questions with the worst answers across the board. Questions F2, F5, S4, S5, S6, and E2 became the focal points of the new project and methodology. Instead of addressing these questions and sustainability as an afterthought or something to be retrofit onto an existing design, ideas were brainstormed to address these areas and were reevaluated continually. Using the metric to guide decision-making ensured that chosen ideas would be sustainable or at least improve on the sustainability. Using sustainability as a primary driver in the design has led to the overall improvement seen in the new project.

6.3 ProSEC

A great deal was learned about creating more sustainable designs through ProSEC. By using the sustainability questions a more appropriate method was produced, based on a modification of the developed world system. This began with the design of two pieces of equipment for cutting lenses and diagnosing refractive error. After investigating existing equipment and performing research in the developing world, preliminary prototypes were created and are being tested.

The lens cutter has been developed to the greatest extent having already been prototyped in the developing world. However, the diagnostic tool has also been successfully prototyped and is prepared for testing and eventual redesign. Although the designs of these tools are not complete, the initial prototypes have proven that it is possible for the equipment to be simplified to create a sustainable venture in the developing world. The equipment can be manufactured in the developing world, which will utilize local labor and material resources. It will also be affordable and the required training can easily be provided to even the unskilled laborer. This should allow a business to sustainably produce and distribute inexpensive eyeglasses over the long-term.

6.4 Future Work

There are several areas in which this work can be supplemented in the future. They are primarily in the further expansion of the sustainability questions and their use in evaluating projects, and in the continued development of the new eyeglasses project.

6.4.1 Sustainability Metric and Project Evaluation

This thesis presented the creation of a series of sustainability questions based on information from several reputable sources. However, it may be possible to expand upon these questions based on an investigation of additional sources. Sustainability has become such a focus in our evolving world that new publications may provide new views that could enhance the questions. They could also be improved by an evaluation of other projects. It is possible that certain aspects of sustainability were overlooked based on the specific projects that were assessed. By using the sustainability questions to evaluate a greater number and wider variety of existing projects, new criteria may be established and new questions may be instituted. This may also provide insight into general issues encountered in nearly all projects. There is the possibility that additional questions lead to negative answers often. This will likely encourage new approaches to deal with such common errors.

It would also be valuable to explore ways of formally incorporating this metric into the design process in order to ensure that sustainability is a primary driver. Conceivably, the questions could be useful throughout the process. They can assist in envisioning the future development of ideas and can continually expose sustainability issues that may arise. Perhaps it would be meaningful to formally use the metric for sustainability confirmation at certain major checkpoints and stages of the design process.

Additionally, it would be worthwhile to explore a greater assortment of projects, perhaps not only mechanical. It may be necessary to expand the sustainability questions to cover projects in areas like infrastructure, chemicals, or even medicine. Each of these areas may have a number of concerns that were not inherent to the mechanical projects investigated in this thesis. This will provide insight into more general issues with design for the developing world. It will also create a more universal set of questions that can truly be applied to any design project.

6.4.2 ProSEC

Although many great steps forward were taken in designing the equipment for the new eyeglasses project, there is a great deal more that must be done. In terms of the lens edger, a few steps must be taken back to correct some of the flaws in the design. In reality, too significant a jump was made by trying to redesign the machine for complete manufacture in the developing world. The large number of simplifications all coupled together led to issues with accuracy and precision and the overall ability to achieve all of the goals set forth. In order to avoid this coupling effect, each simplification should be designed and tested on its own. This will determine whether the concept itself is imperfect. These concepts can then be paired to examine whether any of the combinations cause poor results. Eventually this will lead to all of the simplified concepts being combined into a final prototype. This process will hopefully ensure that the final design meets all of the requirements.

The diagnostic tool also requires considerably more work. First, the design must be tested in the developed world to ensure accuracy. The actual refractive error can be diagnosed by an optometrist and then compared to the reading from the tool. As long as the results are within the accepted 0.5 diopters for nearly all examinees, the device can be considered successful. Next, the design needs to be prototyped in the developing world. Just like with the lens edger, much can be learned from an attempt to create the design and even more can be learned by trying to correct for any problems encountered. This will provide a strong base for proceeding to a future redesign and prototype.

With both pieces of equipment, it is also questionable whether the immediate solution needs to be entirely manufactured in the developing world. It may be reasonable to use some complex components produced in the developed world in a machine primarily produced in the developing world. It may not be able to simplify a part like the cutting wheel on the lens edger to something that can be manufactured currently. There just needs to be a plan to bring that technology to the developing world for the long term. The immediate solution may be a stepping stone to reduced reliance on the developed world. In the long run, it will be desirable for as many parts as possible to be made in the developing world. This could mean eventually bringing the technology to make those remaining complex parts to the developing world.

Appendix A: Sustainability Evaluation Matrices

Table A-6-1 General Projects Sustainability Matrix

		Leveraged Freedom Chair	IDE Treadle Pump	IDE Drip Irrigation	Laptop
Financial	1	Although it is not necessarily customized to each individual it requires a much slower manufacturing process. This means customers will be reached slower. This is still sustainable.	This is not a customized product but is more complex and does require a slower manufacturing process. So customers can be reached relatively quickly.	This is not a customized product and is simple. The manufacturing process should also be simple. So customers can be reached very quickly.	This product is not customized and is mass produced in the developed world. So those in need can be reached very quickly.
	2	It is difficult to believe that income from sales and repairs can provide balanced income over time, especially at the slower pace of manufacturing and the limited need.	It is likely that this product will need repairs over time which can help supplement the income from initial sales. This should provide enough balance.	This product is so simple that initial sales may peak quickly and then fizzle. It questionable how much repairs may be needed. Therefore, there may be issues sustaining a balanced income over time.	This product was not designed to provide any kind of financial support to the developing world. A business can't be formed.
	3	This is not a seasonal product and therefore there should be no concerns with being unable to generate income at any point in the year.	If the product is intended for farming and irrigation, then it can be considered a seasonal product only used during the farming season. However, it may be possible to use it for general water supply and would be used year-round. The product might also need repair which can be done all year.	Since this product is made for farming it will only be used and likely sold for the farming season. Depending on the length of this season, it may limit the ability to provide income year-round.	This product is not seasonal.
	4	This is a very expensive product (approx. $200). This makes it nearly impossible for anyone to afford outright. A subsidy might be required to lower the price and a loan perhaps through micro-finance would also be needed. This is unsustainable.	This product can be reasonably priced and therefore should be able to allow for profit and employee compensation depending on material costs. However, some pumps are more expensive and may require a loan. This is sustainable.	This product can be reasonably priced and therefore should be able to allow for profit and employee compensation depending on material costs. System size can also likely be altered to allow for various price points. Hopefully financial assistance would not be necessary.	This product is not affordable to anyone in the developing world without significant subsidies and loans. Even then, it will likely only work on a donation basis.
	5	The majority of the materials are likely to be found relatively locally, but perhaps only in more urban settings. A few parts may need to be acquired from major cities or imported. This is sustainable if the appropriate supply chain can be formulated.	This product claims to be manufacturable with local materials. However, the piston-cylinder is a more complex component and it is questionable whether it can truly be made locally. The remaining parts are intended to be based on locally available materials.	It is questionable whether many of these materials can be found locally. Plastics in general are not as readily available and a successful drip system must have proper hosing. A new supply chain might be needed to make the materials available.	Nothing can be purchased locally.
Social	1	While there are many disabled people in the developing world, this is not an overwhelming need. However, it is likely a problem across the globe and not just in a particular region.	Everyone needs water. Also, farming, especially on small plots, is huge in the developing world. This could potentially be used by all of the hundreds of millions on farms throughout the world.	Farming, especially on small plots, is huge in the developing world. This could potentially be used by all of the hundreds of millions on farms throughout the world.	The need is not as great as it might seem. Although it can be useful, it is more of a want than a need. But there are millions that could be reached.
	2	This is certainly an enabling product. This product provides transportation to those who would otherwise have great trouble getting around. It gives them the opportunity to then do other things as well.	This is certainly an enabling product. The need for drinking water and adequate subsistence farming is crucial to people in the developing world. This product enables them to farm more efficiently likely increasing output perhaps giving them the opportunity to sell their surplus.	This is certainly an enabling product. The need for adequate subsistence farming is crucial to people in the developing world. This product enables them to farm more efficiently likely increasing output perhaps giving them the opportunity to sell their surplus.	This is an enabling product in that it can provide children with access to more information. This can improve education in general and possibly give children a road to a brighter future.
	3	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.
	4	This product was partially designed in the developing world with local engagement. Trials led to improvements and greater community buy-in.	This product was designed based on the local needs and has been successfully used in locations across the globe. However, there is no evidence of feedback and assessment that would provide insight for better redesign.	This product was designed based on the local needs and has been successfully used in locations across the globe. However, there is no evidence of feedback and assessment that would provide insight for better redesign.	This product does provide for local community feedback in order to improve the product and better meet the needs of the users.
	5	This product was designed to be manufactured almost entirely in the developing world. Aside from manufacturing some hardware and a few complex parts, everything was made and assembled in the developing world. Repair can also be done locally.	Since the product was designed to be manufactured in the local community, a local workforce can definitely be used. Repair can also be done locally for the same reasons.	Since the materials are not readily available at the local level, it can't be manufactured locally. So no local workforce is required. However, some repairs may be done locally providing work for a few people.	It can't provide for a local workforce since the product can't be made locally.
	6	The manufacturing process required is not too complex nor too menial. Some of the steps may require training depending on the skills available at a particular location. But overall training will be desired.	The manufacturing is relatively simple except for the piston-cylinder. This may require some training for workers.	The current manufacturing requires little skill. However, if the manufacturing were brought to the local level, new skills would be required. This would pose a need for training.	No.
	7	The primary concern is the hazard of welding. Workers will need to be trained on welding safety and provided with appropriate safety gear.	The hazard of welding is a concern, but no other part of the manufacturing or use should pose a problem.	There are no safety concerns.	There are no safety concerns.
Environmental	1	Yes. The design was continually revised to reduce the total amount of material used. Although more reductions may be possible a significant effort was made to be efficient.	Yes. The major components are made from strong, reliable materials and the remaining parts are made from renewable sources.	Yes. The product is simple and only uses what materials is necessary to complete the task. However, all materials are from non-renewable sources.	Somewhat. It uses a bit more material than a typical laptop in order to ensure it is rugged. The remaining components are similar and use the smallest amount of material necessary. However, all the materials are non-renewable.
	2	The raw materials used can be recycled and can therefore come from recylced sources. Also, several components can potentially be reused rather than recycled at the end of the product lifecycle.	The materials can be recycled or reused or come from renewable sources.	Some parts may be cannibalized from a broken system to make a new one. The remaining plastic components may be recycled depending on the particular material used.	Some parts may be recycleable, but it does not seem like they are recycled. The entire product is likely garbage when it stops working unless it is a battery issue.
	3	The use of power tools and welding equipment will require the use of electrical energy. It must simply be monitored to reduce waste. Operation only requires human energy.	The use of power tools and welding equipment will require the use of electrical energy. It must simply be monitored to reduce waste. Operation only requires human energy.	The only energy used is during manufacturing which can be monitored to reduce waste. Operation requires little to no energy and would come from a human source.	This product utilizes a battery and/or electrical outlet power. The battery is highly inefficient and unsustainable for the developing world. Electrical power is also difficult to use due to inefficient transmission systems.
	4	Water resources are not used.	Although it is a pump for water, the product itself does not consume any.	The drip irrigation system is intended to make the most efficient use of water for farming.	Water resources are possibly used during manufacturing and can be monitored to limit waste.
	5	No waste is produced through operation and waste produced through manufacturing can be limited. This will likely be in the form of scrap material.	Waste would primarily be in the form of scrap materials left over from manufacturing. The process produces limited waste.	Waste would primarily be in the form of scrap material. Manufacturing produces limited waste.	The battery will eventually become waste that must be disposed of properly. Other waste will be in the form of scrap material and other manufacturing byproducts.

Table A-6-2 Eyeglasses Projects Sustainability Matrix

		Ad-Specs	Focusspecs	U-Specs
Financial	1	This product is designed to be mass produced and is therefore capable of reaching people very quickly.	This product is designed to be mass produced and is therefore capable of reaching people very quickly.	This product is designed to be mass produced and is therefore capable of reaching people very quickly.
	2	This product is currently being distributed through a non-profit organization, so a potential business model has yet to be developed. However, based on its design, it would be difficult to form a developing world business.	This product is currently being distributed through a non-profit program, so a potential business model has yet to be developed. However, based on its design, it would be difficult to form a developing world business.	This product is currently being distributed through a non-profit program, so a potential business model has yet to be developed. However, based on its design, it would be difficult to form a developing world business.
	3	This is not a seasonal product.	This is not a seasonal product.	This is not a seasonal product.
	4	This product costs approximately $19 for the non-profit which does not allow any room for profit or employee compensation. So the cost would need to be much higher, which may not be affordable without subsidies or loans.	This product costs approximately $4 due to advanced manufacturing and mass production. Even if this only covers material costs, the final cost to the customer would likely be reasonable and still provide for profit and employee compensation.	The cost is low due to mass production.
	5	No. The core components are all injection-molded plastic. The rest are also likely not available at a local level.	No. The core components are all injection-molded plastic. The rest are also likely not available at a local level.	No. The core components are all injection-molded plastic. The rest are also likely not available at a local level.
Social	1	This is a pervasive need throughout the developing world. Approximately 1 billion are in need globally.	This is a pervasive need throughout the developing world. Approximately 1 billion are in need globally.	This is a pervasive need throughout the developing world. Approximately 1 billion are in need globally.
	2	This product provides sight which can be conceived as a basic human need. In general it is an enabling product because the gift of sight will likely provide more opportunities.	This product provides sight which can be conceived as a basic human need. In general it is an enabling product because the gift of sight will likely provide more opportunities.	This product provides sight which can be conceived as a basic human need. In general it is an enabling product because the gift of sight will likely provide more opportunities.
	3	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.	There is no reason to believe that this product would be in violation of an local customs, beliefs, or perceptions.
	4	No. The product does not really provide any opportunities for assessment and feedback. It is also unlikely that the product can be redesigned for improvements.	No. The product does not really provide any opportunities for assessment and feedback. It is also unlikely that the product can be redesigned for improvements.	No. The product does not really provide any opportunities for assessment and feedback. It is also unlikely that the product can be redesigned for improvements.
	5	Manufacturing can't be done locally although minor repairs may. Therefore there is little provision for a local workforce.	Manufacturing can't be done locally although minor repairs may. Therefore there is little provision for a local workforce.	Manufacturing can't be done locally although minor repairs may. Therefore there is little provision for a local workforce.
	6	Since manufacturing is not done locally there is little that can be provided in terms of skills and training.	Since manufacturing is not done locally there is little that can be provided in terms of skills and training.	Since manufacturing is not done locally there is little that can be provided in terms of skills and training.
	7	There are no safety concerns.	There are no safety concerns.	There are no safety concerns.
Environmental	1	The finished product incorporates some material that will not be used. However, it may be possible to recycle this material for use in the next finished product. Overall, all the material used is necessary.	All the material used serves a purpose. It is unlikely that material consumption can be reduced.	All the material used serves a purpose. It is unlikely that material consumption can be reduced.
	2	Depending on the type of plastic used it may be recycleable. However, the fluid is likely non-recycleable along with the sac.	Depending on the type of plastic used it may be recycleable.	Depending on the type of plastic used it may be recycleable.
	3	The manufacturing process requires energy, which can be monitored for efficienct. No energy is used directly.	The manufacturing process requires energy, which can be monitored for efficienct. No energy is used directly.	The manufacturing process requires energy, which can be monitored for efficienct. No energy is used directly.
	4	Little to no water is used.	Little to no water is used.	Little to no water is used.
	5	Limited waste is produced through manufacturing. If non-recycleable, scrap material may be wasted.	Limited waste is produced through manufacturing.	Limited waste is produced through manufacturing.

Appendix B: Skakoon's Design Principles

This appendix includes an in depth description of three of James Skakoon's design principles as described in his book "Elements of Mechanical Design" [1]. We alluded to these in Chapter 5 based on their ability to assist in guiding design. We also express how they might differ slightly for developing world versus developed world design.

Simplicity

The first and likely most important principle outlined by Skakoon encourages the design of simple devices. "Create designs that are explicitly simple – keep complexity intrinsic." [1] Skakoon lays out two major criteria on which simplicity can be judged, thought and knowledge. "The less thought and knowledge a device requires, the simpler it is." [1] This does not mean a device will not require significant amounts of thought or knowledge. However, the end user should need little of either. This is where the challenge lies for the designer.

The application of Skakoon's ideas begins to deviate for developed versus developing world in his proposed methods for achieving simpler designs. For example, he identifies two common techniques, purchasing rather than making components, and specifying components by standards. Both seem far less applicable in the developing world. Financial constraints can make it very difficult to purchase finished products, especially if they are only components of a larger machine. Also, since labor costs in the developing world are drastically lower than the developed world, it is far more economical for someone to spend the time making a part. Similarly, since parts are not being purchased, there would likely be less emphasis on standards like hardware sizing.

Although these techniques might not apply directly, his more subtle technique of using symmetry appears universally applicable. Skakoon acknowledges the paradox in that symmetry often requires additional information, thus making it more complex to make. However, it does reduce complexity down the line.

For the developing world, it is also important to consider an expanded view of what may be considered simple. In the developing world, low cost is the factor in the success of a design [1]. Not only must a part be simple in function, but it must also be cheap. Furthermore, it is imperative to consider the simplicity of manufacturing a design with limited resources and skills. It must be noted that simplicity will look different in various contexts. Simplicity in the developed world may be embodied by cheap injection-molded parts with amortized cost of $1. In the developing world, however, this approach may not be sustainable without very high capital cost – a major hindrance to most entrepreneurship in the developing world. Simplicity in design must take into account limited available resources and processes.

Load Paths

Every mechanical design requires bearing and/or transmission of load. Skakoon discusses the importance of accounting for how the load will be transferred throughout a mechanism. This prevents unexpected failure and provides insight into locations that should be made stronger or stiffer.

In their most basic form, load paths define the flow of internal forces or moments through a part and joints as if the load were a fluid. They are most often represented by a single line or set of lines starting at the application of a load and ending either back at that same location or at an opposing load.

The properties of these paths define how well the load is being transferred. For example, the convergence of paths often signifies a stress concentration which is often a “sore” spot and likely failure point. Paths can also identify less desirable shear and bending stresses which can also cause premature failure if not accounted for properly.

Skakoon provides several desirable goals for load paths: equal distribution of flow lines throughout, shortest and most direct load path, minimize the number of times flow lines converge and diverge, avoid concentrations, use gentle rather than abrupt changes in direction, and avoid bunching around corners [1].

Load paths are particularly useful in gauging the structural integrity and simplicity of overall designs. This can aid in concept generation by limiting the number of poor initial designs. It can also assist in the eventual down-selection of concepts by highlighting the number and severity of weaknesses.

Load paths are also an appropriate substitute for FEA in the developing world. In complex designs in the developed world there is a strong reliance on finite elements methods and software to find stress concentrations and likely failure points. FEA allows one to refine parts in order to gain the best ratio of strength to amount of material. This would not help in the developing world where tolerances are much larger and machining accuracy is not as high. Load paths can be utilized to gauge the relative stresses that exist in most developing world designs and enable them to make necessary changes to the structure. Therefore, the use of load paths for structural analysis is coupled with the simplicity of the design.

Prototyping

Any designer would tell you “there is no substitute for a real, physical model” [1]. Even an experienced designer can have difficulty imagining the actual physical product when it is represented only as a CAD model on a computer screen. As Skakoon notes, “a common reaction…is: ‘It’s much [larger, smaller, wider, deeper, shorter, flimsier, heavier, clumsier] than I imagined!’ (Circle all that apply.)”. Instead of being surprised in the end, prototypes can be used to answer questions along the way.

Skakoon claims that at the most simple level prototypes simulate function, size or form, and process [1]. Functional prototypes can help determine if a concept is viable. Sizing and forming prototypes give information on look, feel, weight, etc. Process prototypes assist in evaluating the manufacturing process. Prototypes can represent any one of these or any combination. The more that is included, the closer it is to the actual final product. However, one must always consider the exact purpose for which a prototype is made so that it can be analyzed and broken down appropriately.

Prototypes can benefit a designer in many ways. Probably the biggest advantage of prototyping along the way is the difference in cost between correcting mistakes found in the end and the actual cost of making a few prototypes to limit edits. Not all prototypes have to be expensive rapid prototype models. Sometimes cardboard and glue models are perfectly acceptable for demonstrating a concept and their cost is almost negligible relative to the overall project.

The cost reasoning may not hold true for cheap, low-tech designs, but the costs can still be justified. Prototypes can also help determine the viability of relatively unproven technology. In the realm of developing world design, much of the technology has yet to be tested. Therefore the cheapest, most crude models can likely provide useful information. In many cases, full analytical or numerical simulation of the relevant physical phenomena may be too cumbersome when a crude prototype may elucidate more design insight. This runs counter to the approach in many modern complex engineered systems such as the Boeing 777, which is hailed as a feat of modern engineering that utilized virtual prototyping to save on cost and time [2]. Unlike complex systems like the Boeing 777, designs for the developing world typically involve fewer sub-systems and may be modeled to scale much more easily.

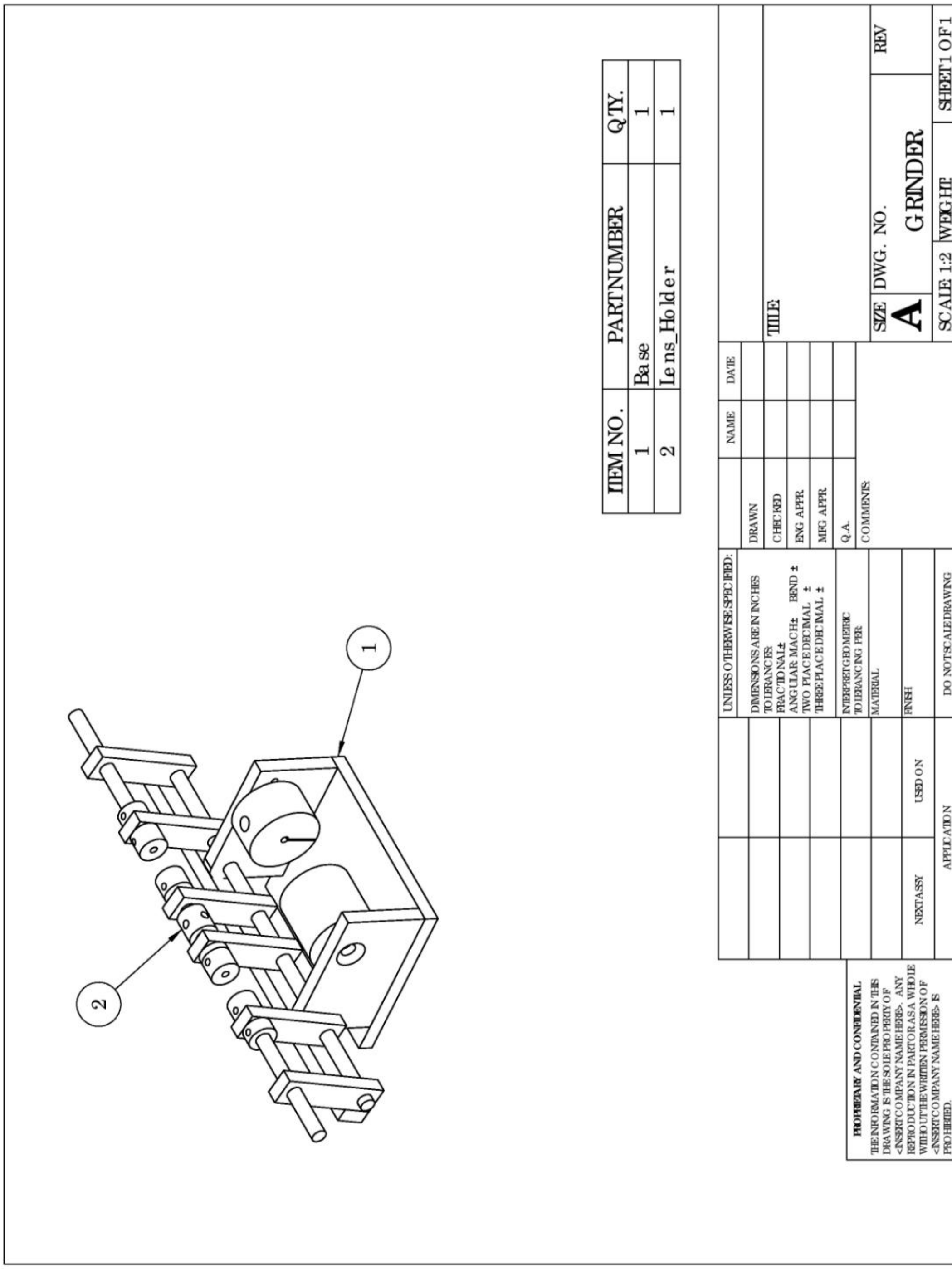
Prototyping is likely an under employed principle. It can be a great complement (or in some cases, a surrogate) for CAD models where the designers can physically see load paths and gain first-hand experience with the manufacturing process. There is also little guidance as to when prototypes would be most beneficial and what kind should be used. Developing world designs are unique in that prototypes should be made more often and at distinct milestones. There is likely also a method for determining which type of prototype should be used at what time. A more methodical approach to production could lead to a more systematic design process overall.

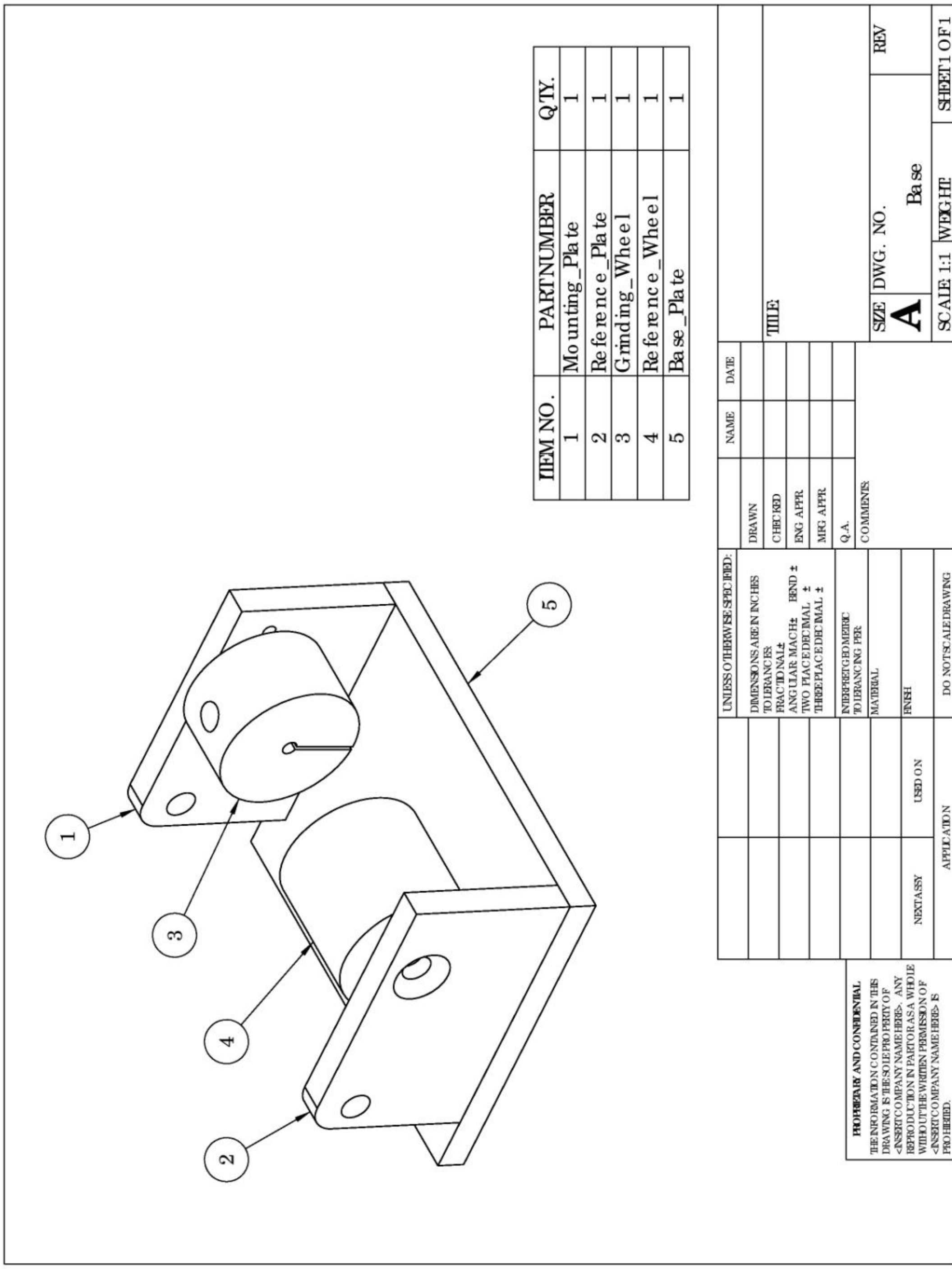
References

[1] Skakoon, J.G., 2008, "*Elements of Mechanical Design*," ASME Press

[2] "Computing and Design/Build Processes Help Develop the 777", http://www.boeing.com/commercial/777family/compute/compute2.html, retrieved on February 25, 2011

Appendix C: Initial Prototype Drawings





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2 Reference_Plate 1
3 Grinding_Wheel 1
4 Reference_Wheel 1
5 Base_Plate 1
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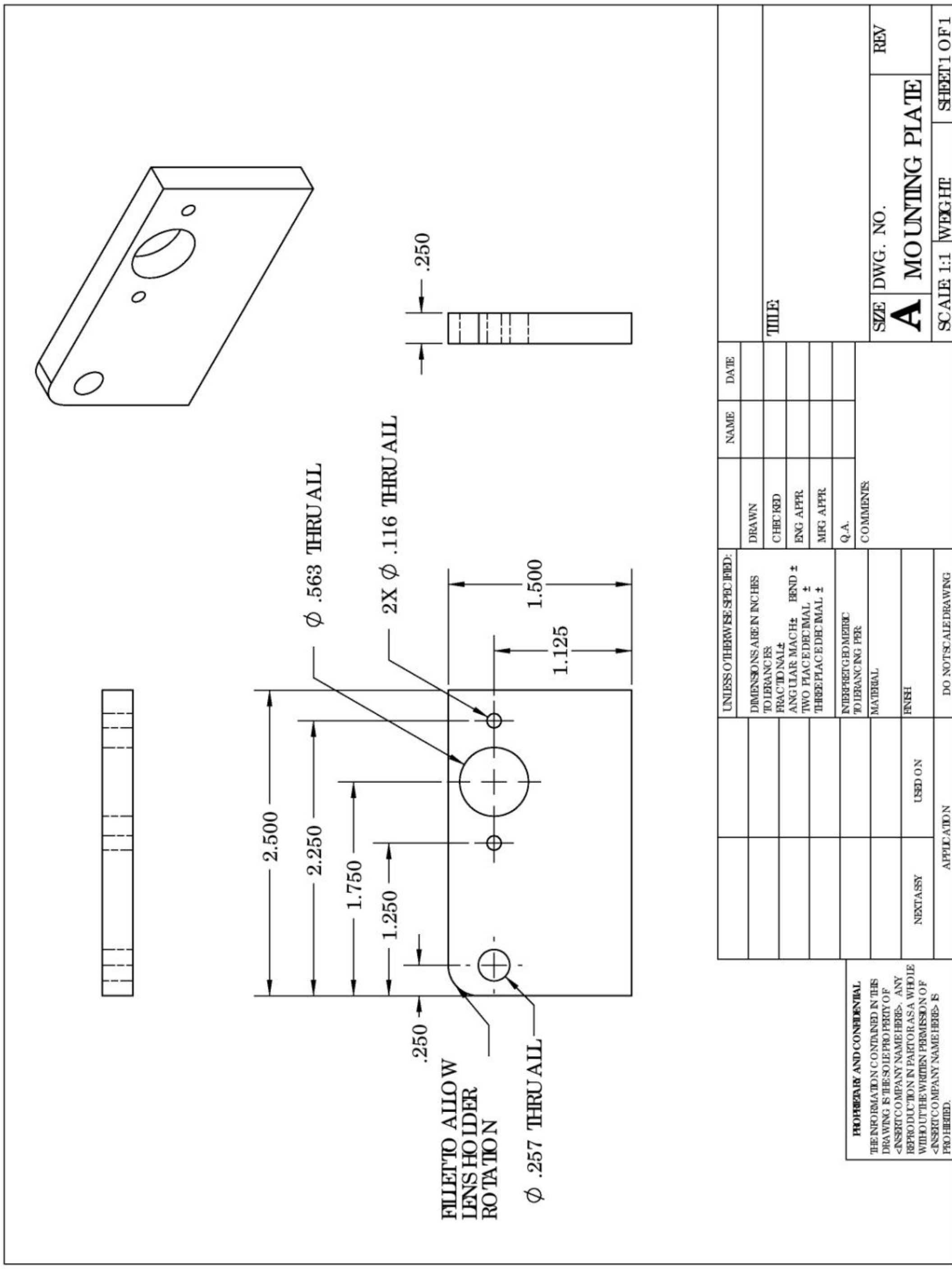

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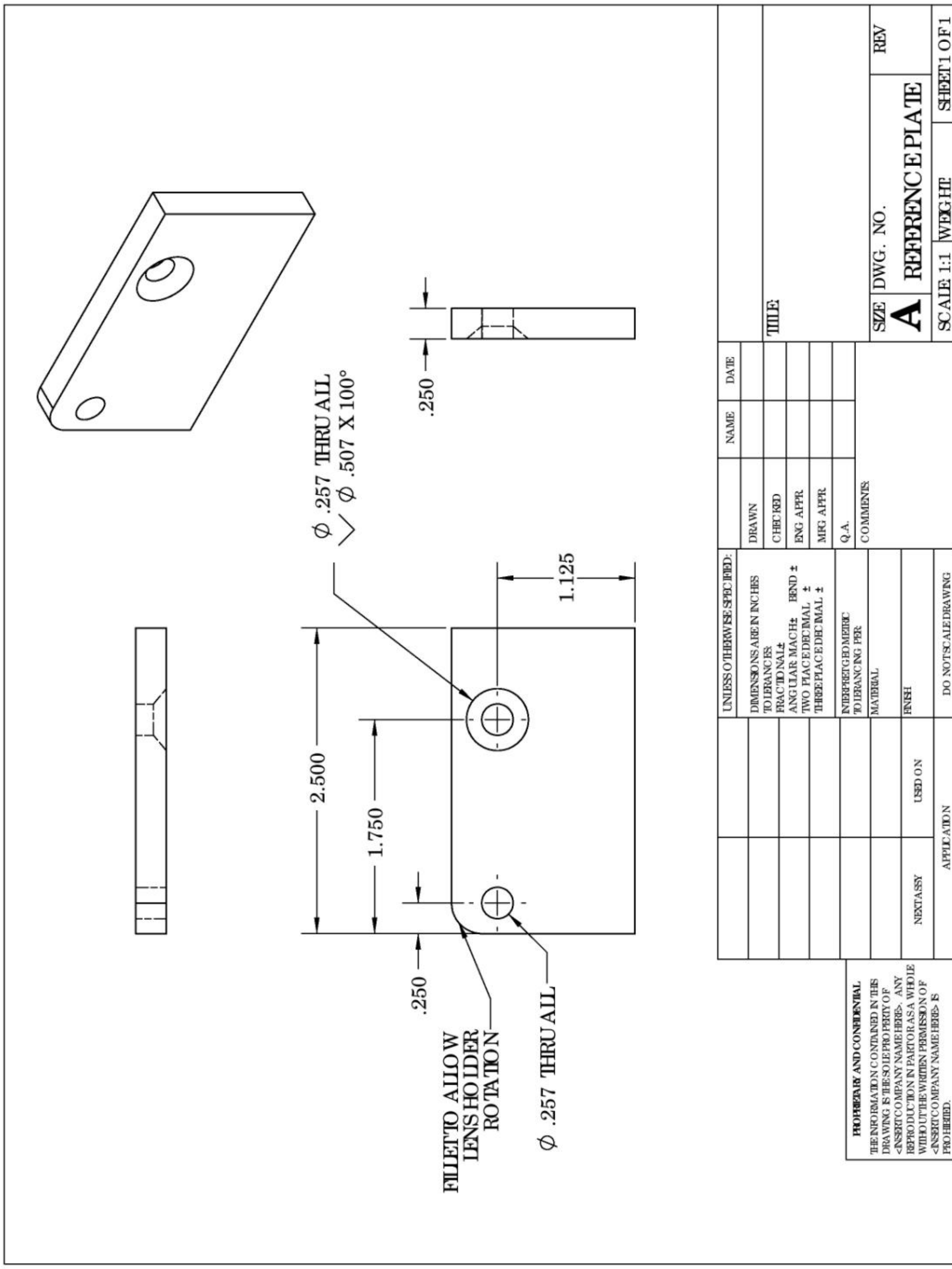
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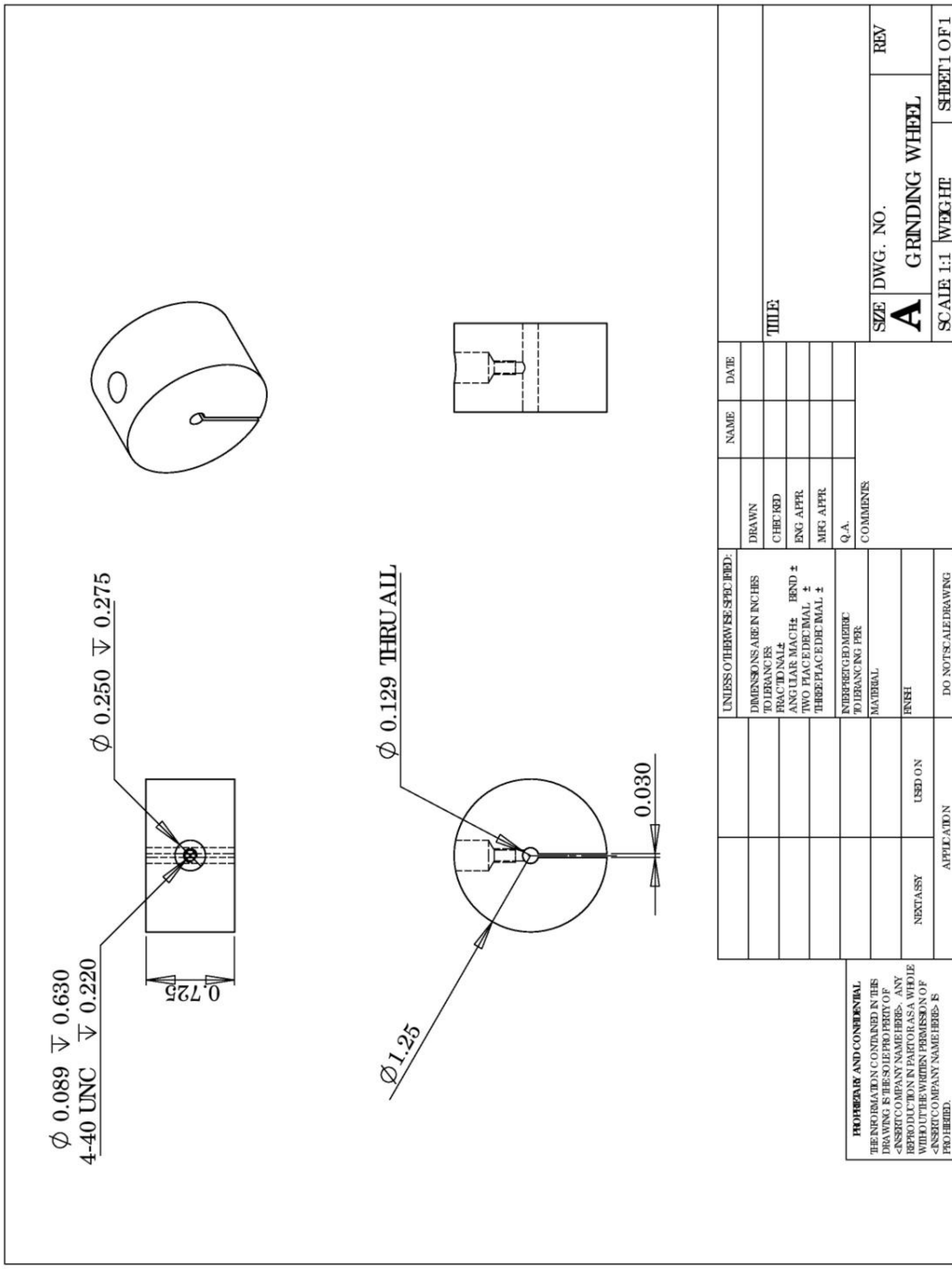

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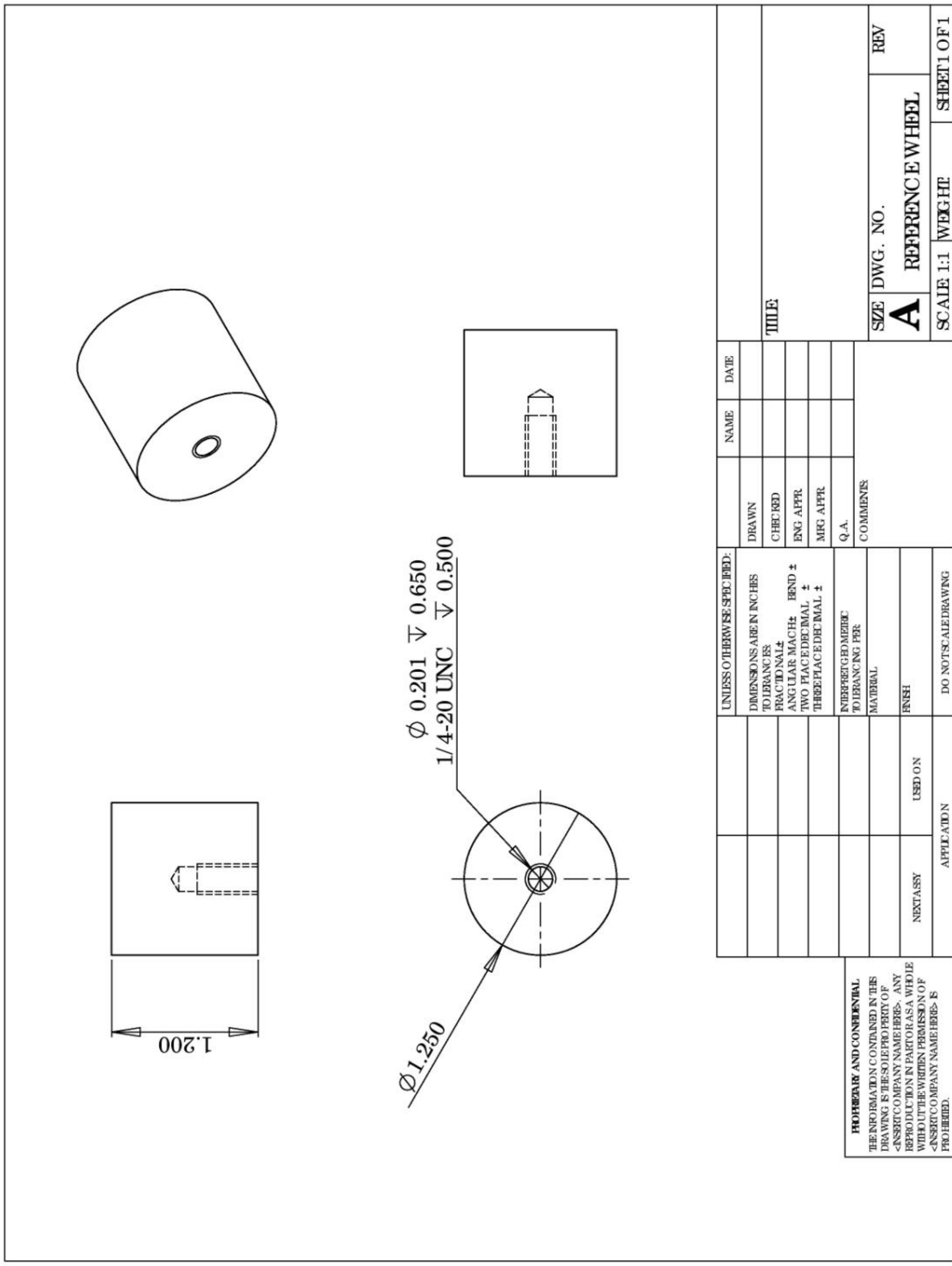

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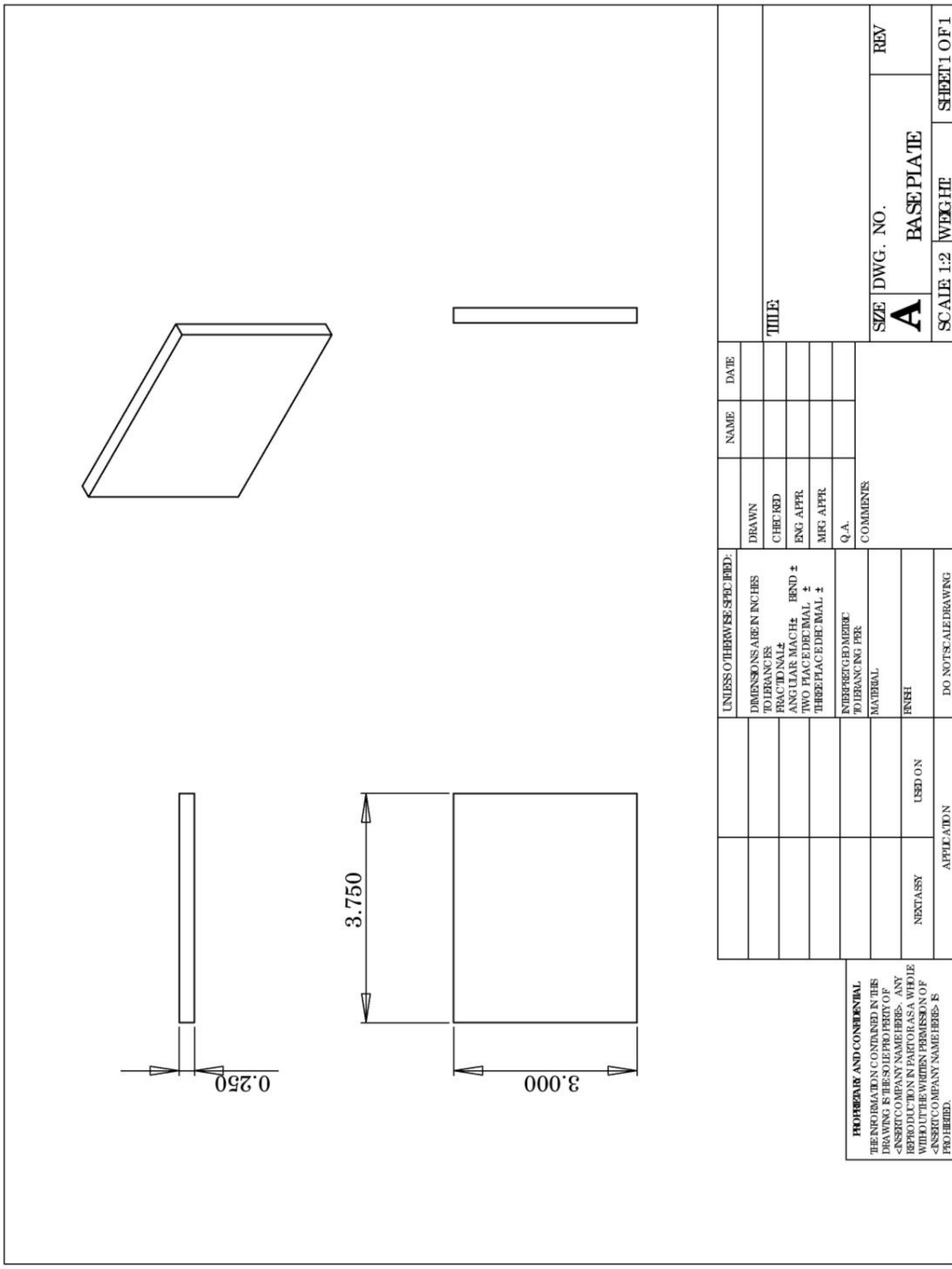
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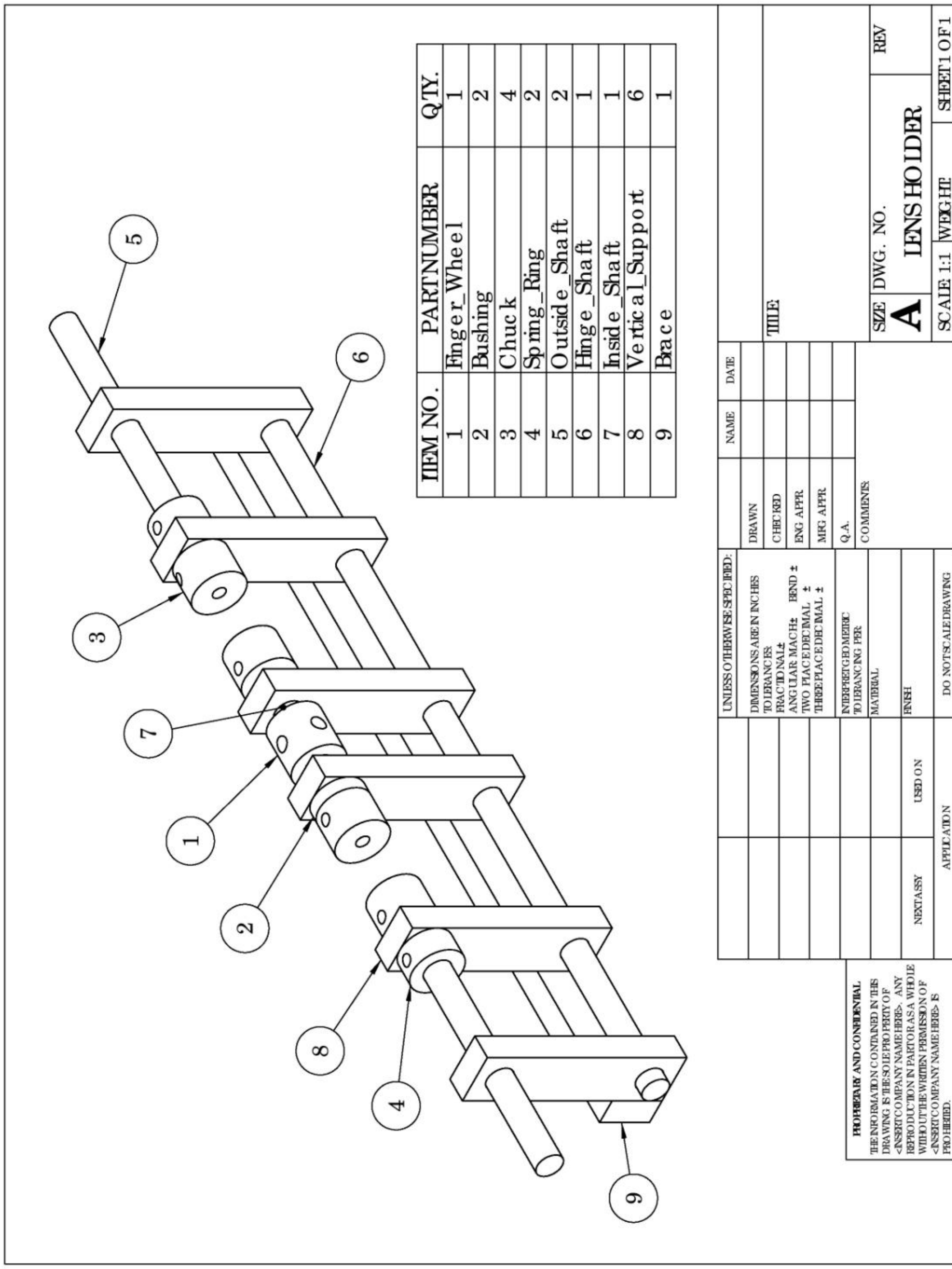

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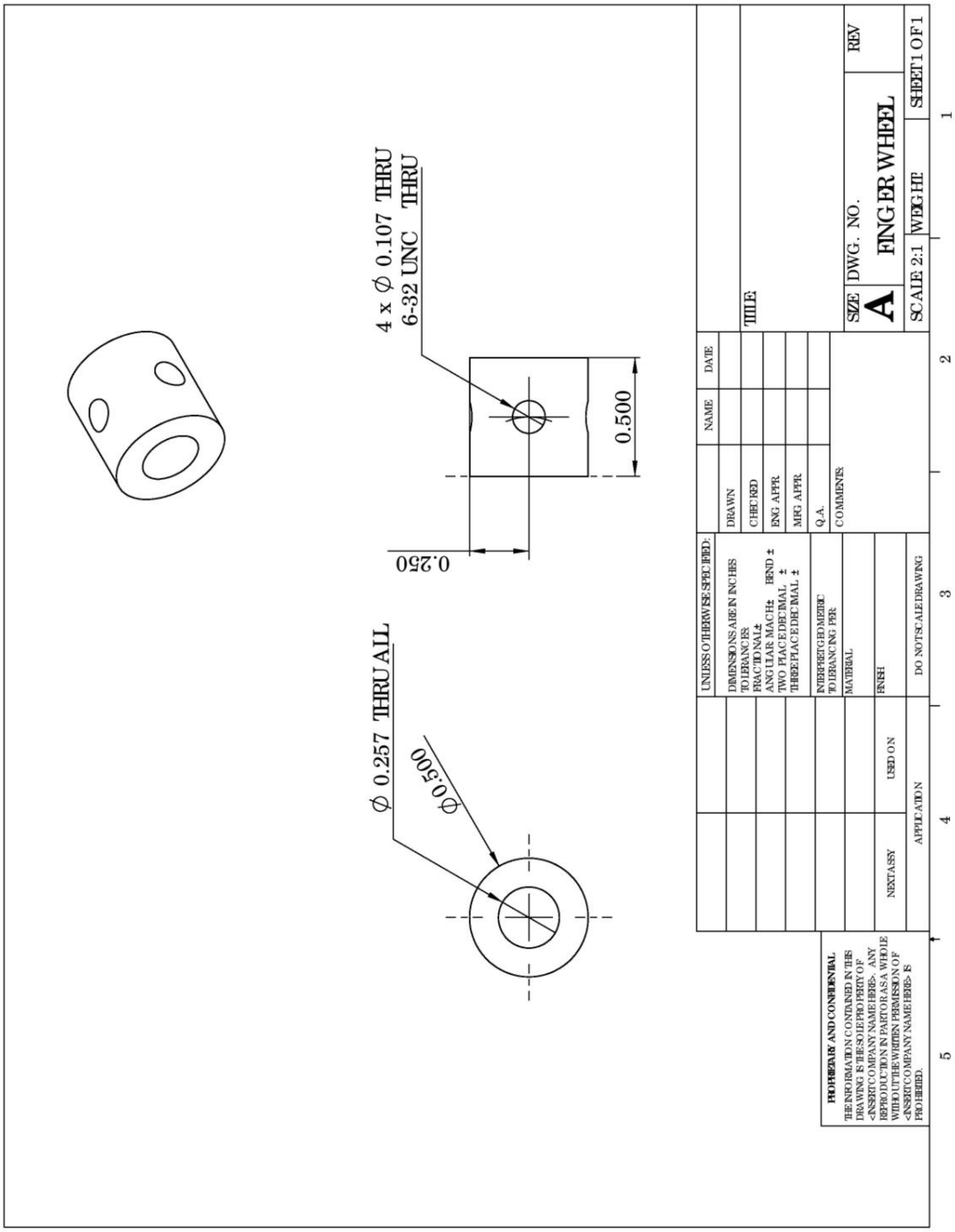
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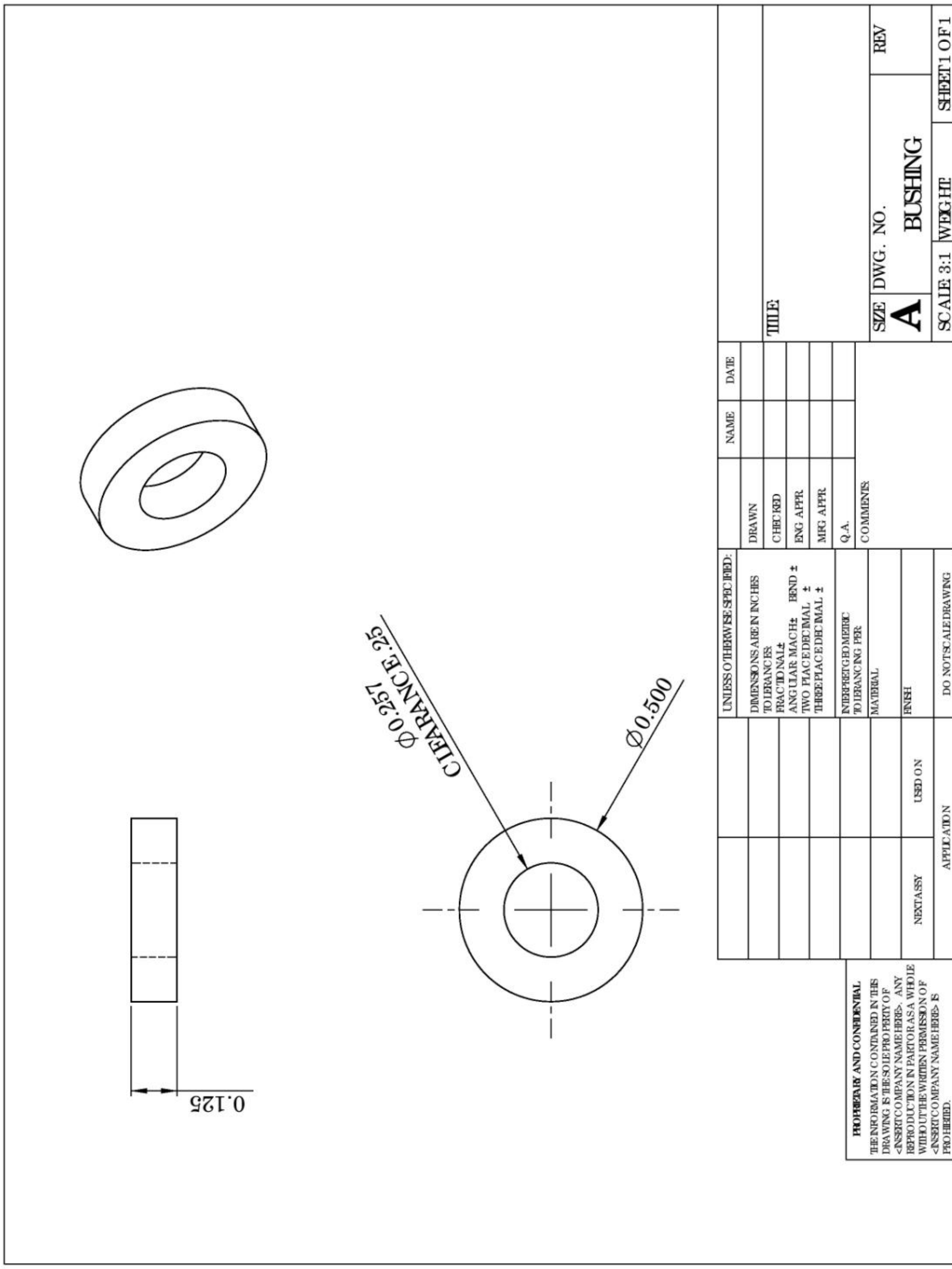

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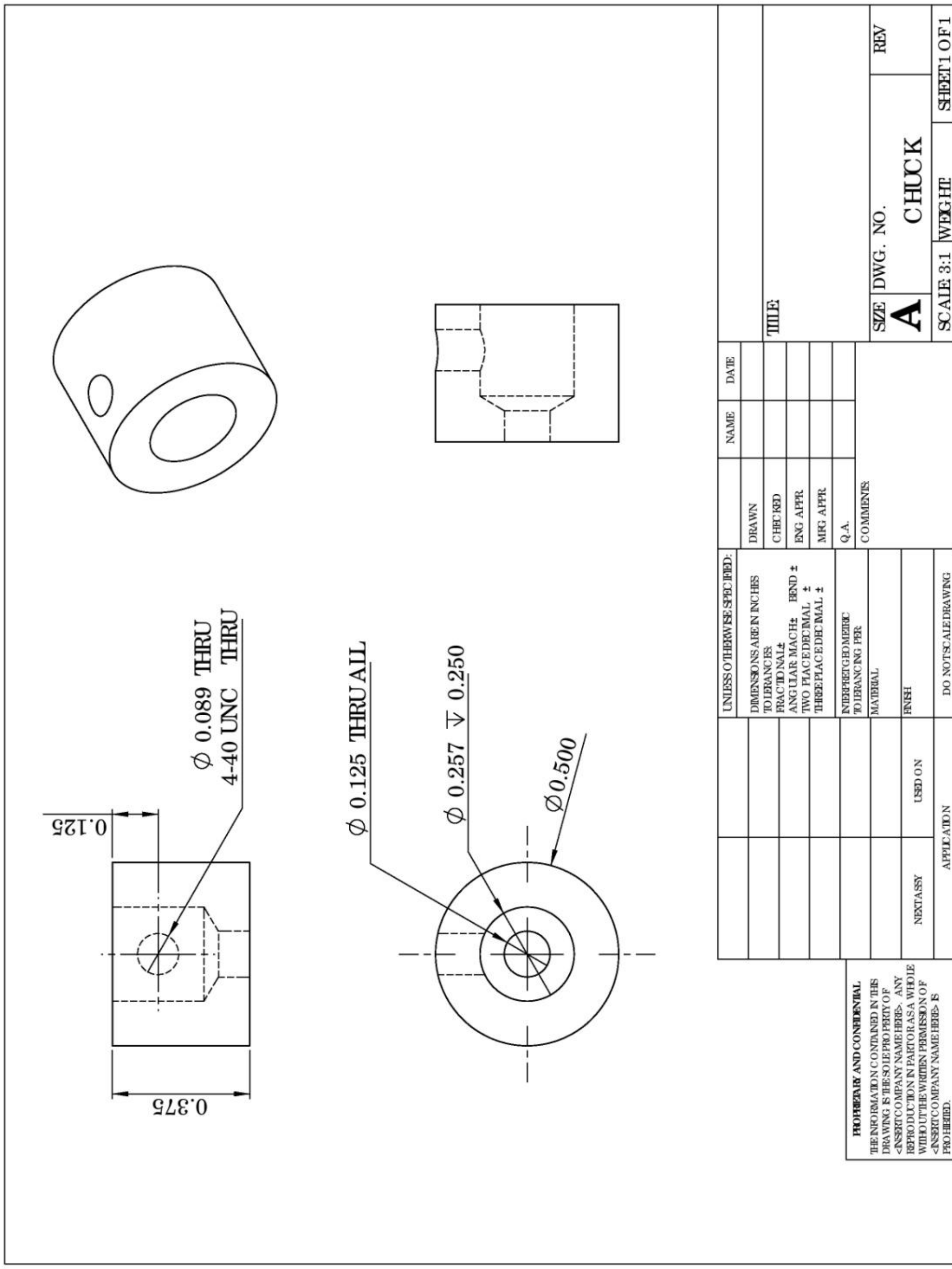
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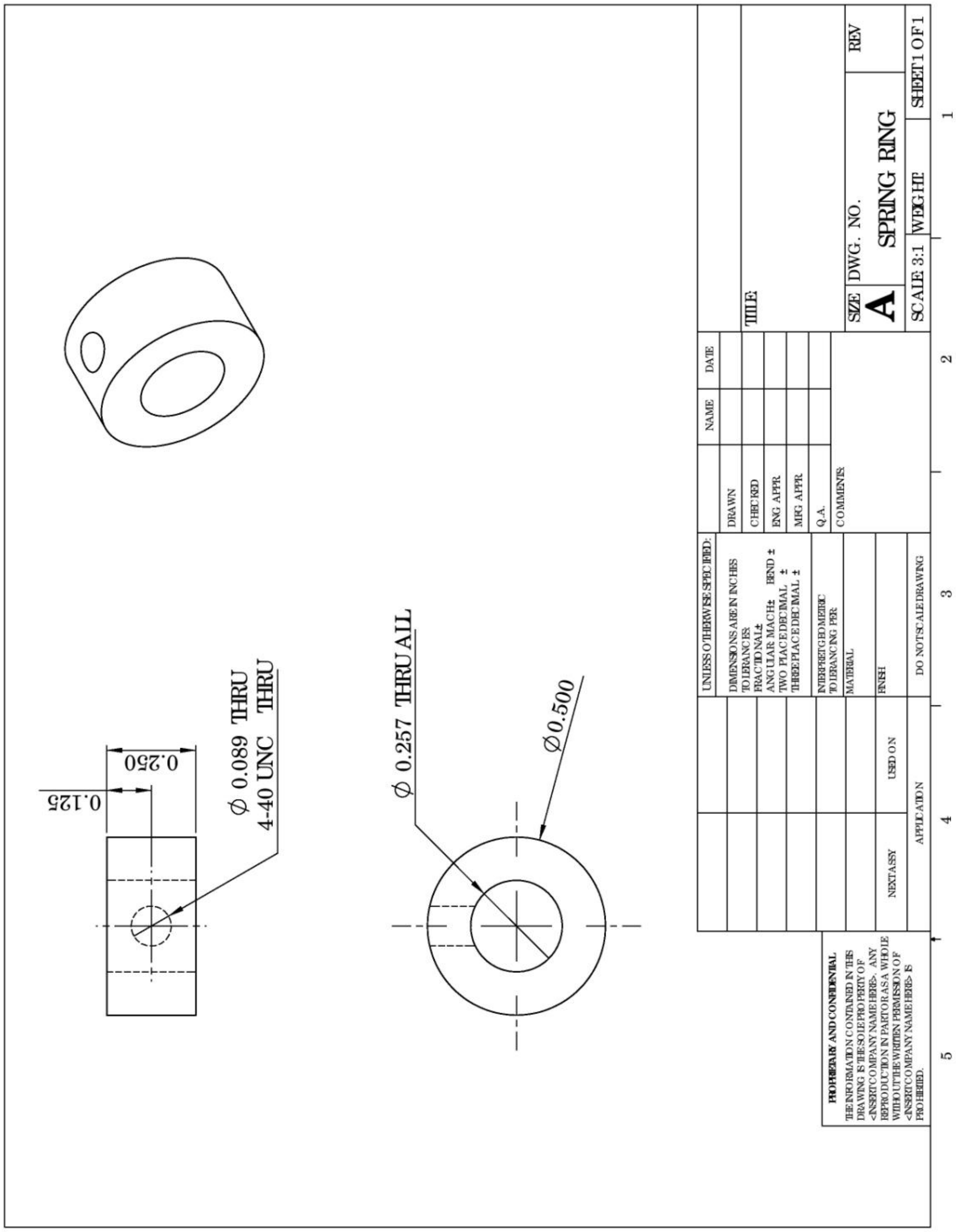
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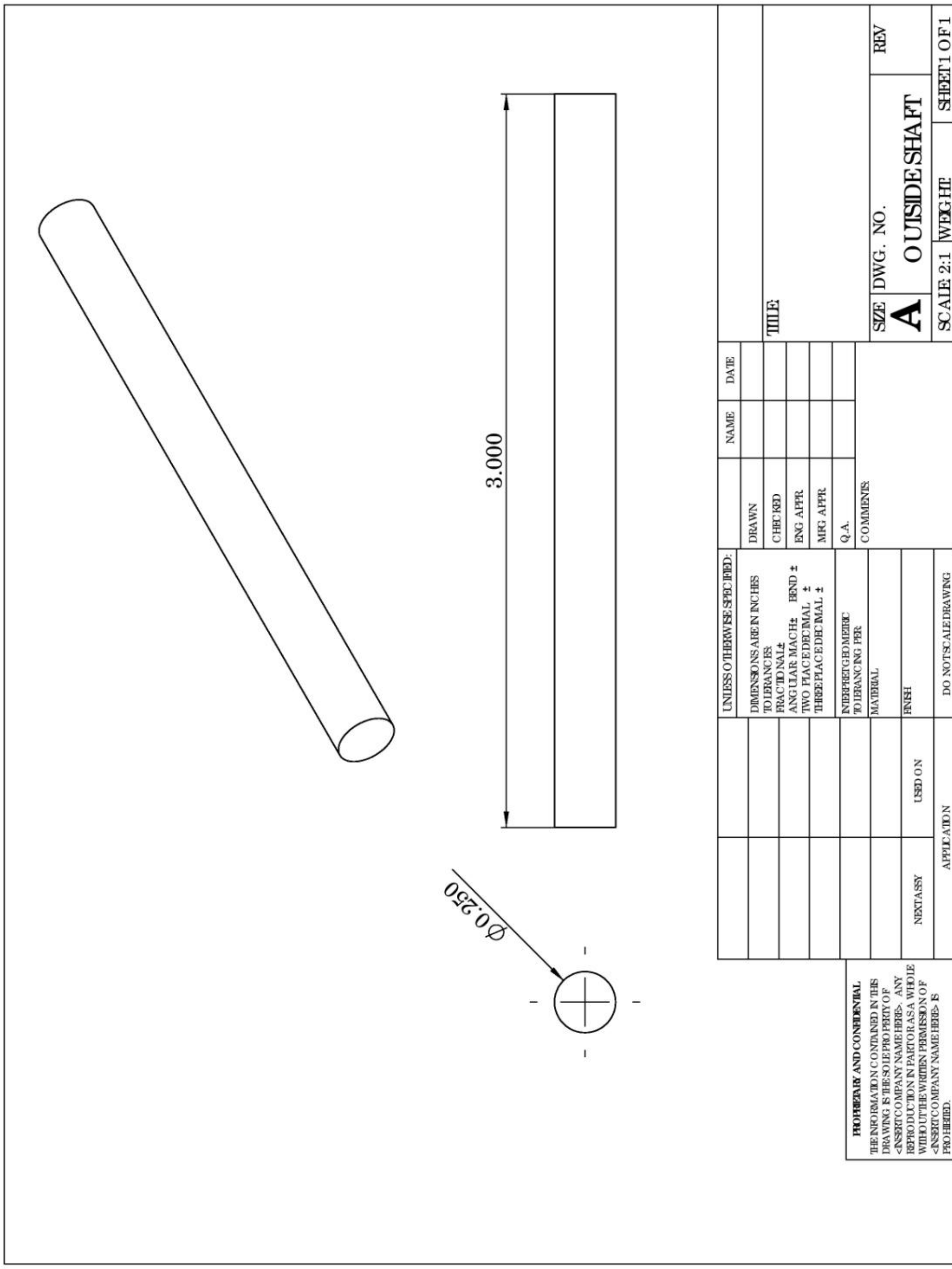

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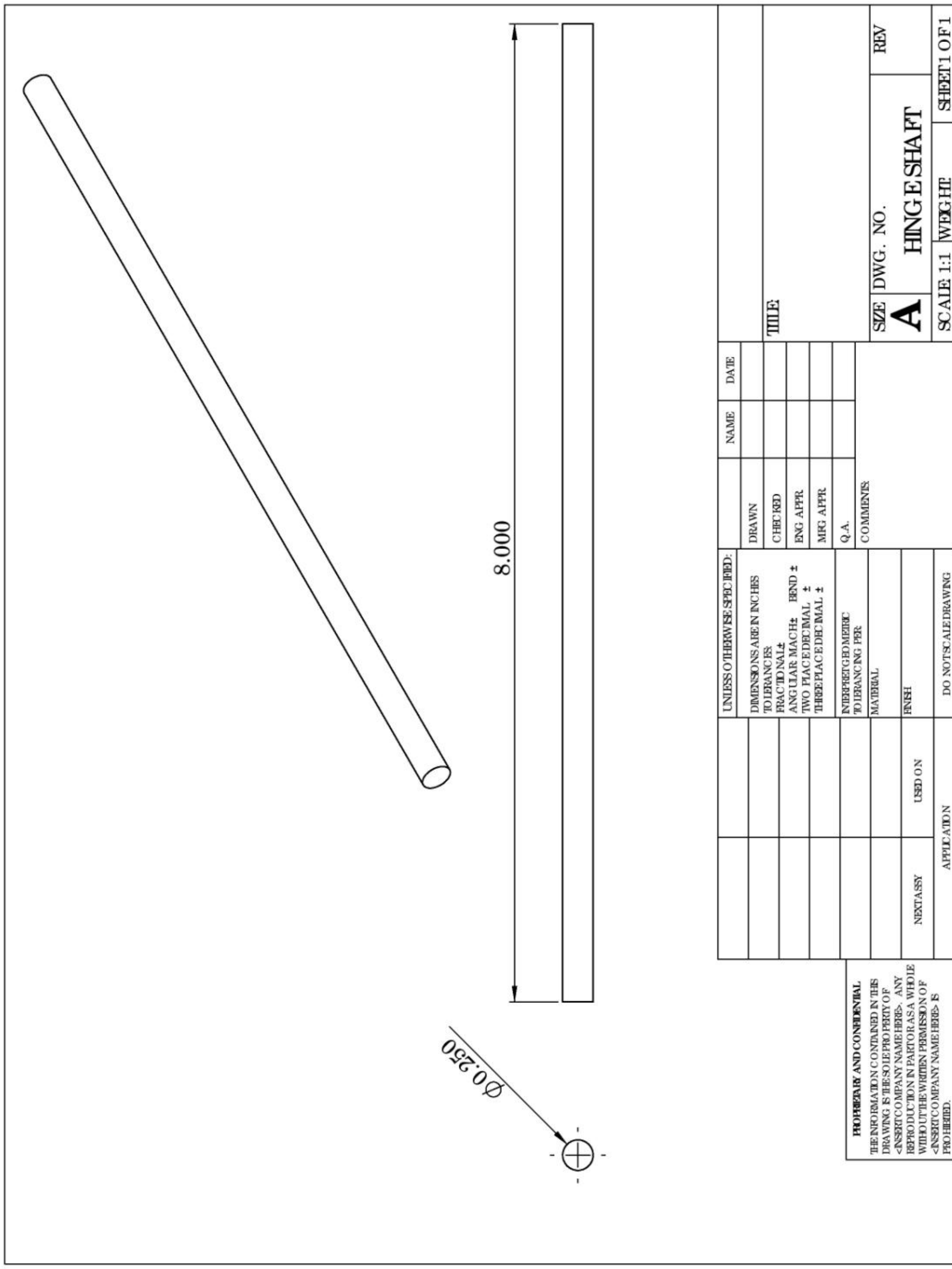
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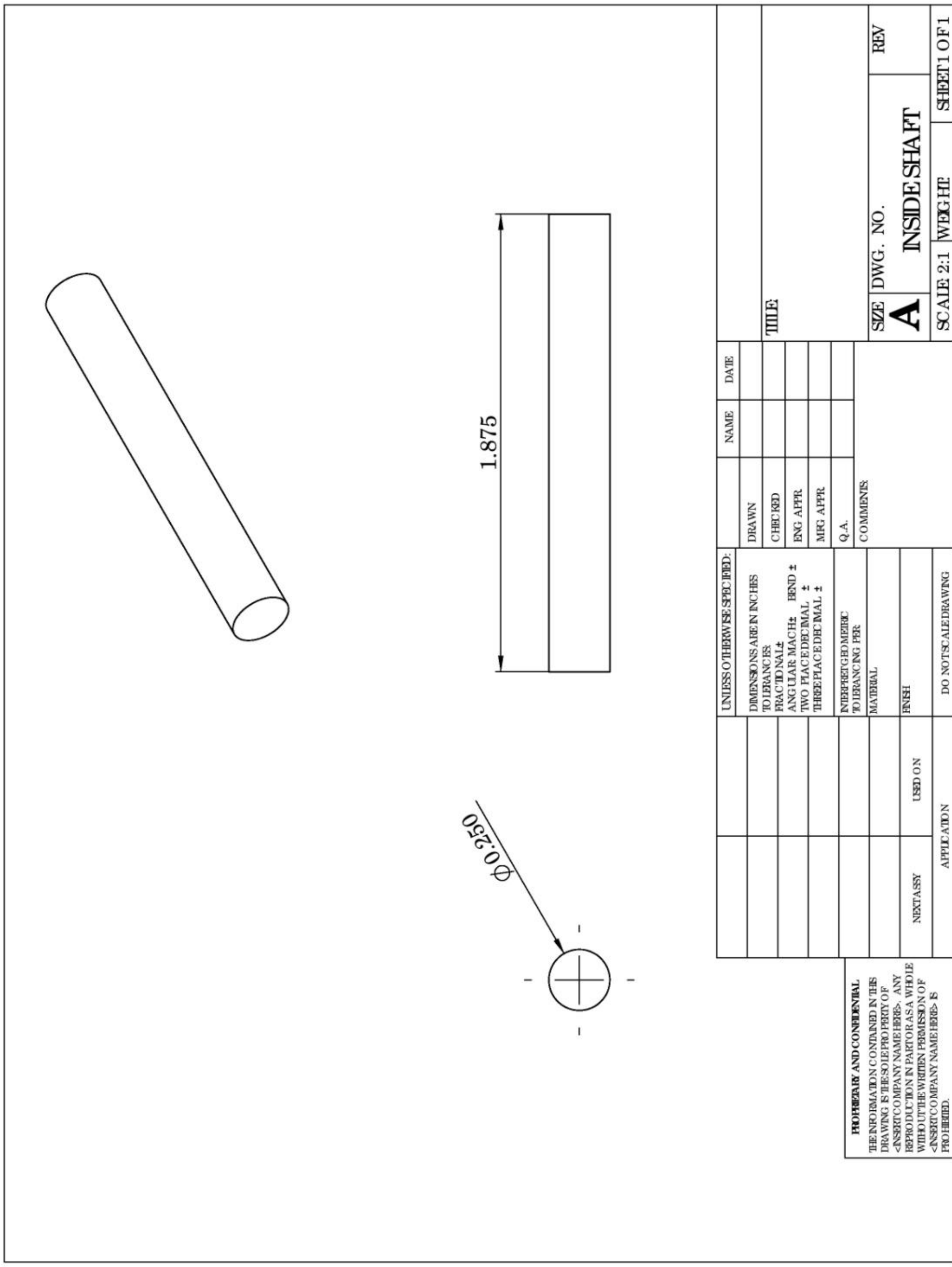

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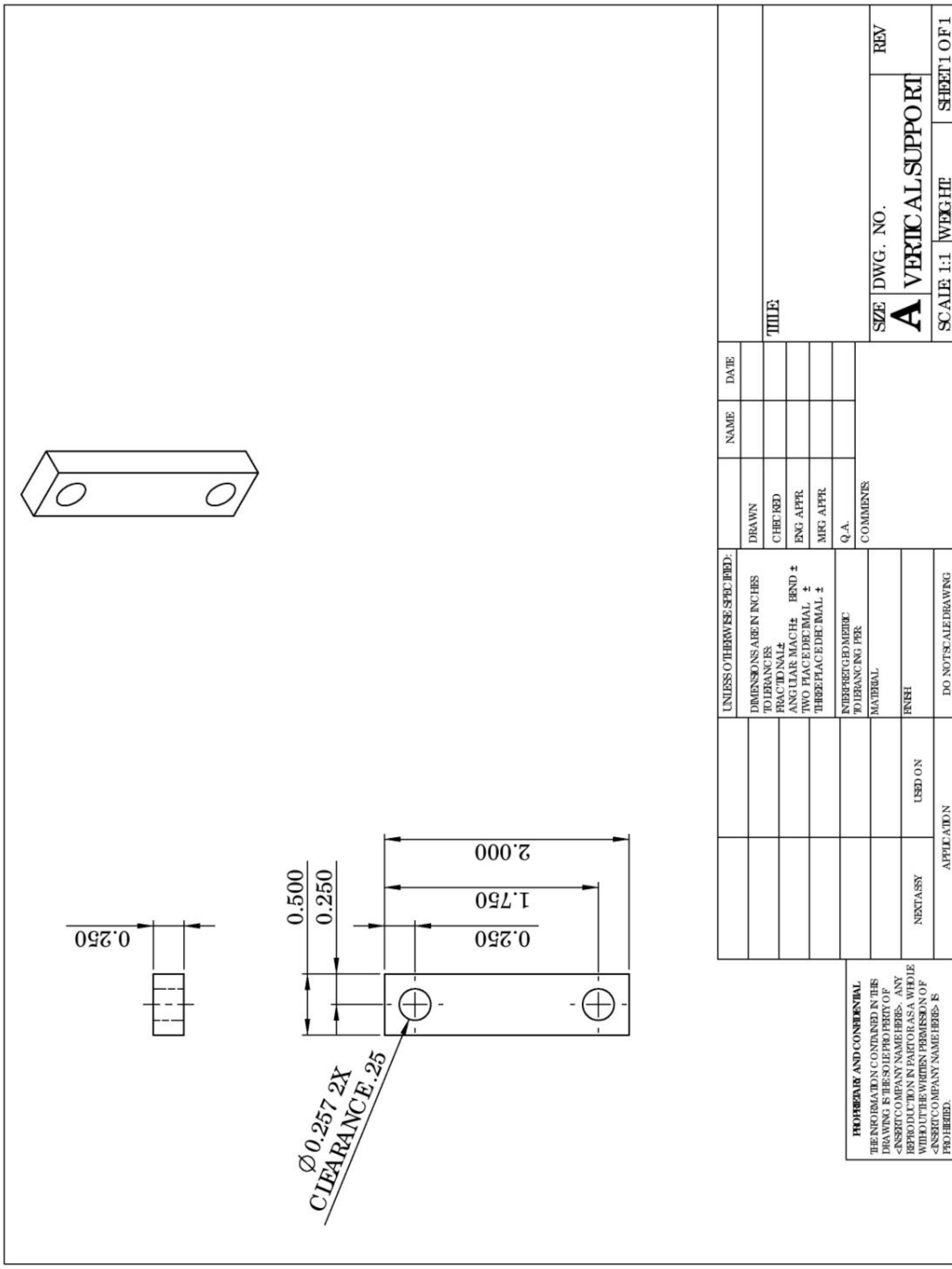
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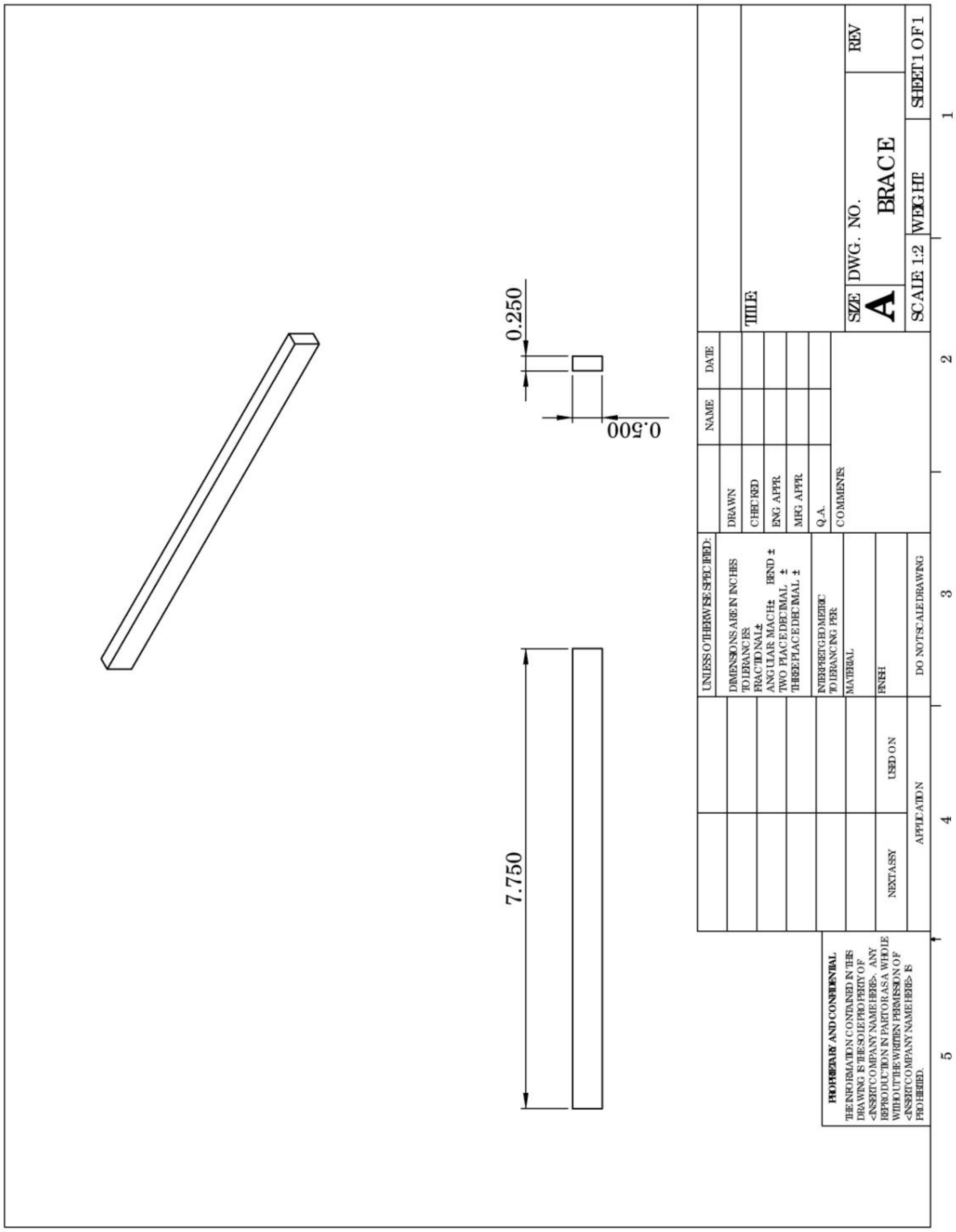
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