Preservation and Progress:

The Socio-Economic and Environmental Effects of Modernizing Zillij Production

An Interactive Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science

Submitted By:
Micah Flock
George Gettel
Stephen Oliveira

Submitted To:
Bland Addison
Tahar El Korchi
Josh Rosenstock

Table of Contents

Table of Figures

Acronyms and Special Terms

APP = Agence du Partenariat pour le progrès
CIA = Central Intelligence Agency (United States)
CO = Carbon Monoxide
CO_2 = Carbon Dioxide
EMIS = Energy and the Environment and Information for the Flemish Region
EPA = Environmental Protection Agency
ESP = Electro Static Precipitator
FODEP = Fond de Dépollution Industrielle
g = Gram
GJ = Gigajoules
Inc. = Incorporated
m = Meter
MCC = Millennium Challenge Corporation
mg = Milligrams
N_2O = Nitrous Oxide
Nm^3/h = Normal Cubic Meters per Hour (Unpressurized)
NO = Nitric Oxide
NO_2 = Nitrogen Dioxide
NO_X = Nitrogen Oxides
O_2 = Oxygen Gas
PM = Particulate Matter
PM_{10} = Particulate Matter Smaller Than 10 Microns
$PM_{2.5}$ = Particulate Matter Smaller Than 2.5 Microns
SO_2 = Sulfur Dioxides
SO_X = Sulfur Oxides
UNESCO = United Nations Educational, Scientific and Cultural Organization
UNFCCC = United Nations Framework Convention on Climate Change
US = United States
USD = United States Dollar
VOC = Volatile Organic Compounds
WPI = Worcester Polytechnic Institute
WTO = World Trade Organization

Abstract

*G*eometric tile mosaic made from glazed terra cotta, known as *zillij*, is a one of the leading artisanal crafts of Morocco. Zillij is an integral part of Morocco's cultural heritage and economic stability, but the production of zillij is not without its environmental side effects. The Moroccan government, with help from the Millennium Challenge Corporation and Arabesque Inc., a leading producer of zillij, are looking for an effective and inexpensive method to reduce air pollution from the wood fired kilns used in zillij production. Our project consists of our research and field work about pollution reduction methods, a cost analysis, and our recommendation for the most effective and efficient method for pollution control.

Executive Summary

Morocco is extremely susceptible to climate change. A change in temperature of just one degree Celsius would significantly reduce Morocco's already diminished water tables, making droughts and low crop yield even more frequent (University of Hawaii at Manoa, 2010). In an effort to reduce Morocco's contribution to global climate change, it became one of the first nations to ratify the Kyoto Protocol. In Morocco's continuous efforts to uphold the Protocol, it has established numerous projects for reducing pollution that is damaging to the ozone layer (Balafrej).

The Millennium Challenge Corporation, a US fund created in 2004 by the US Congress to fight global poverty, has pledged a $697.5 million in the form of a 5 year compact for the development of Morocco's economy. One of the projects sponsored by the Millennium Challenge Corporation is the Artisan and Fes Medina Project. The project aims to modernize and increase major artisanal industries in the Fes region. In addition to stimulating Fes' economy, this modernization seeks to reduce the environmental impact of Morocco's artisanal industries.

One of these artisanal industries is *zillij*. Zillij is a form of geometric tile mosaics made from glazed terra cotta. Zillij tiles are fired in kilns that have remained unchanged for hundreds of years. These kilns use wood scraps and olive pits as a fuel source, which when burnt produce a thick black smog consisting of particulate matter, carbon emissions, and oxides. The particulates can easily be inhaled, and the smaller particles, those smaller than 2.5 microns, can become lodged in lungs causing numerous health problems. Additionally, burning wood produces oxides of nitrogen, oxides of sulfur, and carbon monoxide and dioxide, major contributors to global climate change. In an effort to reduce air pollution, the Moroccan government, with funding from the Millennium Challenge Corporation, has started an initiative to replace traditional wood-fired kilns with modern natural gas kilns. However, these natural gas kilns do not work well for the production of zillij tiles. Zillij tiles have been perfected to have two distinct properties: zillij tiles must break without shattering (an important part of shaping the tiles), and the glaze must remain vibrant after many years in the sun. However, the tiles baked in natural gas kilns are brittle, the colors are dull, and the glazes become rippled. This damage can perhaps be attributed to a lack of airflow through the natural gas kilns. Even with these known problems, the Moroccan government has been unwilling to withdraw its recommendation and consider other pollution reduction methods.

The purpose of this project is to research different pollution reduction methods in the firing of zillij tiles and recommend the most efficient and cost effective solution. To evaluate other pollution reduction methods, we used an economic analysis, specifically a cost/benefit analysis, to compare the socioeconomic costs of the proposed solutions. We also considered externalities that existed in zillij production and case studies to evaluate the effectiveness of alternate air pollution control methods. Our main source of information was Arabesque Inc., a Moroccan zillij company who has sponsored this project out of concern for this important Moroccan industry as a whole. Arabesque Inc., established in 1928, is a family company that has been highly successful in the Moroccan zillij market. Their success has transcended cultural and even national boundaries, as Arabesque Inc. now has an installation in the New York Metropolitan Museum of Art, and is currently supplying zillij for the construction of one of the biggest mosques in America, located in Orlando Florida. The managers at Arabesque Inc. were able to answer our questions and show us how zillij is made. We toured the workshop and kilns, and saw both traditional and natural gas types of kiln.

Our team's main goal is to reduce the harmful emissions caused by wood burning stoves while preserving the traditional methods of zillij production. We researched multiple solutions, including attempting to rectify the issues with gas fired kilns, but determined that the best solution involved retrofitting the current wood fired kilns with emissions scrubbers. Scrubbers are devices that remove particulates and gaseous pollutants from emissions. Scrubbers are an attractive solution because they have low capital costs, since they reuse existing infrastructure, very high efficiency, and do not disrupt traditional production methods. We considered a multitude of different scrubbers and settled on a type of scrubber called a venturi scrubber. A venturi scrubber is extremely simple and has very few moving parts. Exhaust enters the scrubber where it is met by water droplets sprayed from water jets. Using impaction and diffusion, particulates and gases are absorbed by the water droplets. The clean air is released and the water droplets are collected, recycled, and reused. Venturi scrubbers are extremely efficient at removing particulate and gaseous pollutants, removing between 70-99% of all particulates between 0.5 and 10.0 microns, the most dangerous and common particulates produced by burning wood (Air Pollution Control Technology Fact Sheet – Venturi Scrubber). Venturi scrubbers could be installed such that one could service two kilns. Venturi scrubbers do however use water and the waste water containing all the harmful pollutants will need to be disposed of properly.

Venturi scrubbers offer the best balance between efficiency and cost within the operating parameters of zillij manufacture.

Table 1: The savings from using venturi scrubbers (case studies 1 and 2) instead of natural gas kilns over the next five years.

	Capital cost per kiln	Capital cost to replace 240 kilns	Additional operating expense per firing	Additional yearly operating expense per kiln including fuel and maintenance	Estimated 5 year cost including installation, maintenance, and fuel for all 240 kilns
Natural Gas Kiln	$100,000	$24,000,000	$20	$7,300	$25,752,000
Case Study 1	$77,000	$9,240,000	$33	$12,045	$12,130,800
Case Study 2	$82,000	$9,840,000	$15	$5,475	$11,154,000

The chart above shows data gathered from two cases studies focusing on the costs of venturi scrubbers, performed by EMIS (Energy and the Environment and Information for the Flemish Region). The information on natural gas kilns was obtained during our field work. As the chart shows, the cost to replace all 240 traditional kilns with natural gas kilns is significantly greater than retrofitting two existing kilns with one venturi scrubber. Additionally, the projected operational costs are significantly lower.

Based on our findings, we have decided that adding a venturi scrubber to the existing wood fired kilns is the best solution (figure 1). Following this recommendation would allow Moroccan artisans to continue using traditional methods to make zillij, while addressing the problem of air pollution and climate change. The skills of zillij artisans have been handed down generation by generation, a slow evolution through nearly a millennia of refinement. To suddenly disrupt this with gas powered stoves and synthetic glazes would do an extreme disservice to the rich heritage of Morocco's handicraft industry. Zillij artisans rely on delicate traditional methods to produce their extraordinarily beautiful and durable mosaics, and the high aesthetic standards of Moroccan zillij will be preserved through the use of our recommendation.

.

Figure 1: A computer rendering of the proposed scrubber/kiln solution.

Acknowledgments

We would like to thank:

Our generous sponsors at Arabesque Inc. for their assistance and expertise, without which our project never would have existed.

Our advisors for coordinating this amazing experience, and their assistance in conceptualizing and producing this project.

Walid Mourhrib, our Moroccan student aid, who helped us in translating certain sources that were in Arabic and French.

Meriem Sahli, our Arabic teacher at AUI, who through endless patience managed to teach a bunch of engineers some Arabic

The Morocco 2012 Team, for making this trip fun and enjoyable while also offering friendly support when we needed it.

Thanks Mom, Dad, and Rebecca for all your encouragement during the project! Also for all your continued support as I continue to finish my degree without which none of this would be possible. -Steve

Authorship

Abstract (Written by George Gettel, edited by Micah Flock)
Executive Summary (Written by Stephen Oliveira, edited by entire team)
Introduction (Written by Micah Flock, edited by entire team)
Background
    Artisans in Morocco (Written by George Gettel, edited by Micah Flock)
    Traditional Methods of Zillij Production (Written and edited by Micah Flock)
    Pollution in Morocco (Written by Stephen Oliveira, edited by entire team)
    Alternate Methods of Pollution Control (Written by George Gettel, edited by Micah Flock)
Methodology (Written by Stephen Oliveira, edited by entire team)
Findings and Analysis
    Gas Kilns (Written by Micah Flock, edited by entire team)
    Pollution and Morocco's Economy (Written by Stephen Oliveira, edited by Micah Flock)
Conclusions and Recommendations (Written by George Gettel, edited by entire team)
Appendices (Written and edited by entire team)

1. Introduction

The dawning of the 21st century is bringing the world into a more globalized age. Economic effects aside, this increased global awareness demands that nations, even developing nations like Morocco, work in an international context to become environmental stewards as well as economic powers. People in these nations are beginning to realize that they are part of a larger world, and therefore must take on new responsibilities to care for the wellbeing of the global community.

Morocco has quickly adopted these responsibilities, especially concerning the environment. As a nation that is extremely susceptible to drought and is dependent on agriculture, Morocco is very concerned about the side effects of global climate change. By 2020, the average temperature in Morocco will rise by .6 - 1.1 degree Celsius. This increase in temperature would cause a water loss of 10 - 15% and 10 - 50% lower agricultural yields depending on the yearly rainfall. This is especially troubling because the frequency of droughts in Morocco has increased to one out of every two years compared to the one out of every five years observed in 1990 (University of Hawaii at Manoa, 2010). These concerns have made Morocco a leader in pollution reform. Morocco was one of the first nations to ratify the Kyoto Protocol. In its continuous efforts to uphold the Protocol, Morocco has established many projects for reducing pollution (Balafrej). While these projects are potentially very good for the wellbeing of Moroccan citizens, some projects have the consequence of hurting traditional artisans, who are being forced to find new means to produce their goods.

Zillij, geometric tile mosaics made from glazed terra cotta, is a one of the leading artisanal crafts of Morocco. Vibrant zillij tile is used to decorate walls, floors, fountains, and mosques all around the Arab world. Zillij is an integral part of Morocco's cultural heritage, but the production of zillij is not without its environmental side effects. Zillij tiles are traditionally baked in wood fired kilns. In addition to wood, these kilns use sawdust and olive pits for fuel, which produce thick black smoke when burned. The Moroccan government, with help from the Millennium Challenge Corporation, a fund dedicated to ending global poverty, and Arabesque, our sponsor and a leading producer of traditional zillij, are conducting tests to determine the feasibility of switching from the use of wood fired kilns to modern natural gas fired kilns. Arabesque has found that while natural gas kilns emit less pollution, the tiles produced in them are not suitable for zillij. Tiles fired in natural gas kilns are too brittle to be used in zillij production, and the natural glazes they use do not finish properly in these proposed gas kilns.

The push to modernize traditional artisanal tools such as wood-fired kilns has created tension between the Moroccan government and artisans. The government is seen as too eager to accept an inadequate solution, and artisanal companies like Arabesque are concerned that hastily changing to modern methods of production will harm them and lower the quality of their craft. Our project's mission is to gather information on the firing of zillij and research alternative modern options to reduce the pollution created by the process while preserving traditional production techniques and the history associated with them. With that information, our sponsor Arabesque Inc. proposes to send the Executive Summary of this report, including its findings and recommendations, to the Moroccan government in hopes that the government will take steps to develop a more effective and comprehensive solution to the pollution problems created by zillij manufacturing.

2. Background

This chapter will cover general information concerning Morocco, its artisans, the problem of air pollution in Morocco. It will also contain more specific information about traditional zillij production. The first section gives an overview of present day Morocco and artisans. The second section concerns the production of zillij. The third section will look closely at pollution created by zillij and the Moroccan government’s attempts to slow global warming. This information will provide insight into the country of Morocco and pollution created by zillij.

2.1 Artisans and Morocco

Morocco stands out as one of the world’s most promising developing nations. It has also always been a cosmopolitan country, a cultural melting pot of European, African, and Arab traditions. Morocco is beginning to develop as an economic force and capitalize on its resources, location, and rich cultural heritage to drive its economic development. Morocco’s economic growth comes with an increasing global awareness about Morocco’s environmental responsibility to its people and to the world. However, Morocco’s thriving artisanal industry is a double-edged sword. Artisans use traditional methods to make their goods, some handed down from a time when environmental responsibility was not a major concern and therefore they involve some practices that are a threat to both health and the environment. As one of the first nations to ratify the Kyoto Protocol, Morocco has a responsibility to reexamine the traditional methods that artisans use, and help the artisans reduce their environmental footprint.

2.1.1 Morocco's Place in the World

Morocco is a developing country with a great deal of potential for growth. Political pressures from citizens, international organizations, and local women's rights activists (particularly in the wake of the Arab Spring) have created a more liberal environment for all Moroccans to live and prosper in. Globalization has also helped Morocco achieve a steady state of economic growth benefiting a large portion of the population, while providing a new global awareness of human rights. Despite some benefits, this free market economic policy and encouragement of corporate development is taking a heavy toll on traditional culture, artisans, and the environment. The migration of rural Moroccans to cities is removing the traditional Moroccan cultural identity and replacing it with a modern commercial identity (Agrawal 2008). People such as rural artisans who hold on to their culture are having a hard time adjusting their traditional approaches to generate revenue in a changing world (Agrawal 2008). The Moroccan government has recognized this loss of its artisan cultural identity and has since started to create and finance programs and trade schools to promote local artisans and protect the local cultural history and traditions (Wadi Bellamine, 2007).

2.1.2 Comparative Advantages of Morocco and Other Nearby Economies

Compared to Morocco's neighbors, Algeria and Mauritania, Morocco is the most modernized, and by far the most politically and economically stable. Morocco has been working very hard to increase its trade relations with the western world and has been widely recognized for its advancements in government and society (CIA World Fact Book 2012). Morocco has gained an advanced status with trade and political relations with the European Union, showing its ability and desire to improve their economic status. It is also the first and only African country to enter into a bilateral Free Trade Agreement with the United States. Free trade agreements are good for Morocco as it lowers export costs for companies that are willing and have the means to enter the global market.

However, not many Moroccan artisans are capitalizing as much as they could on tourism and the growing export market. Artisans in similar markets such as those in Tunisia and Turkey are more successful than Moroccan artisans because they capitalize on tourism better (US Government, 2012). Artisans can utilize the opportunities that the Moroccan government offers to gain an edge on the artisans in other Arab countries. This edge could potentially allow Moroccan artisans to export their goods and increase their global market share. To encourage artisans, the Moroccan government and aid organizations have invested in plans to train artisans.

2.1.3 Organizations Helping Artisans in Morocco

In Morocco, there are many humanitarian groups and organizations working with Moroccan artisans to help promote artisan goods by directly networking with other artisans or lobbying the government.

The Peace Corps first arrived in Morocco in 1963 and currently have 4,000 volunteers in Morocco ("Peace Corps Country Overview" 2012). They established a small-business sector in 1999 to work with artisans. This sector works to improve product quality, encourage women to join the workforce, encourage new or more profitable designs and techniques, and to teach artisans business skills.

The World Trade Organization (WTO), another organization working in Morocco, is a group that advises and lobbies governments on behalf of small businesses ("Further trade reforms would improve economic efficiency" 2003). In Morocco, the WTO is very active and has identified areas that could benefit artisans if better regulated. The WTO has already helped to lower tariffs and create trade agreements with surrounding and Western nations. Currently, the WTO is advising the Moroccan government to increase export incentives and increase loans to small businesses. The WTO focuses on exports and lowering tariffs as cheap exporting drives economic growth and promotes greater security.

The most relevant of these groups to our project is the Millennium Challenge Corporation. The Millennium Challenge Corporation was created in January 2004 by the United States Congress to fight global poverty. The corporation offers aid to countries that apply based on "good governance, economic freedom, and investments in their citizens" (mcc.gov). Upon approval, the applicant receives either a compact (a large 5-year grant for applicants that meet all criteria), or a threshold program (a small grant for applicants that do not meet all the criteria, but are committed to policy improvement) (US Government, 2004).

In August 2007, Morocco was granted a 697.5 million dollar compact to increase productivity and employment based on the Moroccan government's Plan Emergence, a national growth strategy started in 2005 (Millennium Challenge Corporation, 2007). The Millennium Challenge Corporation granted the compact to ensure that the poor would benefit from growth created by the government's plan. Currently, the compact is funding five projects:

Artisan and Fes Medina Project, Enterprise Support Project, Financial Services Project, Fruit Tree Productivity Project, and Small-Scale Fisheries Project (US Government, 2012).

The Artisan and Fes Medina Project's goal is to preserve artisanal trade by increasing the links between artisans and tourists. The strategy is to increase the quality of artisanal wares by training artisans in modern production techniques and business management. Training in modern production techniques will be provided to 50,000 master artisans, and 3,800 artisans will receive production assistance. Thirty new careers will be added to the public artisan schools to diversify access to artisanal jobs, which will improve employment and income (Millennium Challenge Corporation, 2007). Specifically, the agency in charge, the Agence du Partenariat pour le Progrès (APP), has created loans for the replacement of wood fired kilns with modern kilns (US Embassy, 2007). The APP has allocated 111.87 million dollars for the Artisan and Fes Medina Project. This project has also been promised support from UNESCO and the World Bank to stimulate Fes's economy. FODEP (Fond de Dépollution Industrielle), a German fund devoted to preventing industrial pollution, has also promised its support (Millennium Challenge Corporation, 2007).

The effectiveness of aid programs is promising but the benefits have not been universally distributed. Foreign investment has been a boon to some artisans in Morocco, but there is a long road yet to travel for the handicraft industry overall.

2.2 Traditional Methods of Zillij Production

Traditional methods for zillij production have been in use since the 14th century (Housefield, 1997) (see appendix A for additional information about the history of zillij tile). The process has been refined over the years to produce tiles with two important properties: zillij tiles must break without shattering, and the glaze must remain beautiful after years in the sun.

Our project team, at the generous invitation of Arabesque Inc., toured a zillij factory on the outskirts of Fes. There, we spoke with local artisans and were walked through the process of zillij production, where we took the pictures that illuminate this section (higher resolutions available upon request).

The clay used by Fes zillij artisans is sourced from the side of a valley on the outskirts of Fes. This particular clay is unique to the Fes region of Morocco, and is one of the few places in the world that has the required composition and consistency of clay to produce zillij. Clay is transported from the mines to the kiln facility, about 2km away. At the kilns, the raw clay is put into pools of water to absorb moisture and become workable (figure 1).

Figure 2: Water is added to the clay so that the clay is soft enough to work with.

As shown in figure 2, the clay is mostly grey, marbled with tan and black. As it moisturizes, the clay darkens in color and becomes workable. Once the clay is sufficiently soft, it is brought inside to be shaped into tiles (figure 3).

Figure 3: An artisan pounds a tile into shape. Note the pile of tile edges in front of the artisan.

Balls of clay are pounded flat until they are the proper thickness for tiles. The artisan then uses the hammering instrument as a guide to cut the tiles to size. The edges of the hammer are beveled to ensure the tiles are properly beveled as well. The scraps of clay produced by cutting the tiles to size are piled up and then sent back to the clay pools to be recycled. Cut tiles are stacked around the artisan. When there are enough tiles, they are transported to the roof of the facility to dry and bake in the sun. This is the first of three heating cycles, and it is the most gentle. Tiles are transported by hand to the drying area, where they are laid out in a dense grid (figure 4).

Figure 4: Tiles dry in the sun on the roof of the kiln facility.

This grid maximizes the amount of tiles that can be dried at the same time. The tiles must be fully dry before they are sent to the kiln, or otherwise the water in the tiles will vaporize and cause cracking in the final tiles. After a day in the sun, tiles are transported back to storage (figure 5) where they wait until they are baked in the kiln.

Figure 5: Tiles awaiting firing in the kiln.

As can be seen in figure 5, the tiles have taken on a white, almost chalky color. This indicates the tiles are dry enough to be sent to the kiln.

The kilns are handmade almost entirely out of brick and mud. They are a little under two stories tall, set into the building itself. The kilns consist of two chambers, a combustion chamber (figure 6) below a baking chamber (figures 7 and 8). As can be seen in figure 6, there are roughly two dozen holes in the layer of mud and brick that separates the baking chamber from the combustion chamber. These are to allow the heat and smoke to pass through from the combustion chamber. The top of the kiln is open to the air (figure 8 and 9) and heavily ventilated. When the kiln is initially lit, the top and side vents are covered to speed up the heating process. They are uncovered when the kiln is fully lit.

Figure 6: The combustion chamber of the kiln. Note that it is not covered in soot; the kiln is thoroughly cleaned after each use.

Figure 7: The bottom of the baking chamber of the kiln. The vents allow heat and smoke to enter from the combustion chamber.

Figure 8: The top of the kiln, as seen from the inside.

Figure 9: The top of the kiln as seen from the outside, roof level. Note the tiles drying in the sun to the left.

The tiles are stacked in the kiln to be fired. They are stacked in a specific orientation, so as to maximize airflow and evenly distribute air around the tiles (figures 10 and 11).

Figure 10: Tiles stacked in a kiln ready to be fired (Viewed from the top of the kiln).

Figure 11: An artisan stacks tiles inside of a kiln to be fired.

The front of the kiln is sealed with mud (figure 12), and a fire is built in the combustion chamber. The kiln is heated to over nine hundred degrees Celsius, and that temperature is maintained for four hours. The ovens are heated with a mix of wood scraps and olive pits, as well as sawdust. These fuel sources are incredibly inexpensive in the region, and produce the thick, oxygenated smoke that is essential to the manufacture of these tiles. The oven then remains sealed and is left to gradually cool off over night. The firing and cooling process lasts 12-18 hours.

Figure 12: The kiln, sealed with clay and sheet metal, is in use.

Because the firing process takes so long, every kiln facility has two kilns. While one kiln is firing, the other is being emptied out and cleaned in preparation to be filled with tiles. Once the tiles pass through the kiln for the first time, they are ready to be glazed. The traditional glazes used are made from natural pigments and minerals. Cobalt is used to make blue glaze, copper is used to make green glaze, chrome is used to make the red glaze, and iron is used to make brown and red-brown glazes. These glazes rely on the natural oxidization of the metals in them to be successful. The glaze is applied by hand (figure 13). Once the glaze is applied, the tiles are laid out again to dry. Once the tiles are glazed and dried, they are stacked in the kiln again for a second firing. As can be observed in figures 10 and 11, darker colors are put near the bottom of the kiln, and lighter colors are put near the top. This is because there is a temperature gradient in the kiln, and darker glazes need more heat than lighter glazes.

Figure 13: An artisan glazes tile by hand.

Once the glazed tiles are fired, they are transported to another facility in Fes. This is where the tiles are cut and assembled into zillij. The process begins with an artisan tracing the shape of the zillij tile to be cut onto the glazed tile (figure 14).

Figure 14: An artisan traces the shape of a zillij tile onto a tile to be cut.

Once the shape for the cut tile is traced onto the larger tile, the artisan begins the process of cutting the tile to shape. The area around the shape of the zillij tile is cut roughly out of the larger tile, and then is placed against a metal anvil type device. That section of tile is struck with a chisel-tipped hammer (figure 15). This process consists of a series of very precise strikes delivered to the face of the tile, chipping away at it until it is in the desired shape.

Figure 15: An artisan shapes a tile for zillij.

Once the cut tiles are ready, they are finally assembled into zillij. The zillij is assembled face down, and mortar is used to join the tiles together (figure 16). The panels shown in figure 16 are then shipped to customers, who fit them together to install them in their houses.

Figure 16: Sections of zillij ready to be packed for shipping.

2.3 Pollution in Morocco

Morocco is becoming an increasingly environmentally conscious country. The government is pushing for more international regulations to ensure that global climate change does not become worse. Climate change is a serious threat to Morocco and could cause more droughts. One of the proposed measures to reduce pollution is to replace the traditional wood-fired kilns used for zillij with the natural gas kilns used to fire modern ceramics. This potential change is neither easy to make nor ideal for the zillij production process.

2.3.1 Current Measures to Reduce Pollution

Morocco has many measures in place to reduce greenhouse gases, the most important of which is Morocco's signing of the Kyoto Protocol. The Kyoto Protocol was introduced in 1997 as an agreement among countries to reduce greenhouse gases and pollution. For ratification, the protocol requires that the producers of 55% of the world's pollution sign it. Even though the average Moroccan creates a very small amount of pollution every year, Morocco became the 22nd of 165 countries to sign and ratify the protocol (Balafrej).

The protocol promises to reduce greenhouse gas emissions by 5% of the country's 1990 levels by 2012. In addition, there are "carbon sinks" such as planting trees that can be used to offset carbon emissions produced. Morocco has since met these requirements and has even emerged as a leader after the Marrakesh Accords, which reformed the treaty and introduced clean development mechanisms that encourage developing nations to build economic capacity while still adhering to emission limitations in accord with the Kyoto Protocol (UNFCCC). Morocco has a portfolio of clean development mechanisms and has reached out to co-signers such as Italy to show support (Delegates Approve Kyoto Rules, 2001). However, Morocco still believes that these measures are not strict enough to slow global warming, and that the protocol needs to enforce a lower level of emissions (Balafrej). Therefore, Morocco has started pollution reduction measures of its own. One measure, the National Action Plan, funds 25 projects aimed at renewable energy and reducing greenhouse gas emissions (Environmental & Ethical Tourism in Morocco, 2007).

One of the methods that the government has used to reduce air pollution in cities is the relocation of the zillij kilns in Fes. The kilns were moved two miles outside of the city, nearer to the clay mines, but additional government pressure could move the kilns an additional eight miles outside the city. The government has established a city closer to the kilns outside Fes for the workers and their families, but the city is developing very slowly and is at risk of becoming a *bidonville* (a slum). Greatly reducing the pollution from kilns could allow zillij kilns to move back into Fes, and could prevent irreparable damage to the industry and the artisans.

2.3.2 Emissions from Traditional Zillij Kilns

Wood Fired Kilns are fueled with a mixture of scrap wood, sawdust, and olive pits. When wood is combusted a wide variety of particulate matter and gases are released. The particulate matter released during the combustion of wood can include carbon and soot particles, unburned wood dust, polyaromatic hydrocarbons, semi-volatile organic compounds, and ash (Beauchemin and Tampier) (see appendix I for more detailed emissions information). These particles are less than 10.0 microns in diameter and can be categorized by whether they are between 2.5 – 10.0 microns (PM_{10}) or if they are between 0 – 2.5 microns ($PM_{2.5}$). Both sizes of particles are capable of being inhaled, but $PM_{2.5}$ particles are capable of penetrating deep into the human lung and are widely considered a hazardous air pollutant. Of the particulate matter released by burning wood in the kilns, 90% of particles are PM_{10} and 75% of particles are $PM_{2.5}$ (Beauchemin and Tampier, 2008).

While the particles released in wood combustion are the most visible problem in the exhaust, the various gases released are just as, if not more, dangerous. Various gases produced in combustion include oxides of nitrogen, carbon monoxide, carbon dioxide, volatile organic compounds, and sulfur oxides. Other emissions of wood combustion can include dioxins, and furans (Beauchemin and Tampier, 2008).

The main oxides of nitrogen are nitric oxide (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_20) to a lesser extent. These oxides are very harmful and are all large contributors to global climate change even in small amounts. Burning dry wood like wood scraps used in traditional kilns releases 674 mg/m^3 (211 g/GJ) of oxides of nitrogen and burning wood at an extremely high heat can increase this amount. If burnt properly, the oxides are fully combusted and not released. However, incomplete combustion in the traditional kilns produces a large amount of oxides, which would have to be scrubbed out of the exhaust or reignited in a secondary burner system. Oxides of sulfur (SO_x) also occur and can be handled the same way as oxides of nitrogen. Wood is a low-sulfur fuel source and wood releases only 10.8 g/GJ when burnt. However, it is still dangerous and should be scrubbed or reignited (Beauchemin and Tampier, 2008).

Incomplete combustion also creates carbon monoxide (CO) and volatile organic compounds such as tars. In a complete combustion system, the carbon molecules are oxidized to form carbon monoxide, which is oxidized to form carbon dioxide (CO_2). Both of these steps require oxygen in the system to complete. In the traditional kilns, the kilns are sealed and lack air flow. While this method produces beautiful tiles, it causes incomplete combustion leading to the formation of carbon monoxide, volatile organic compounds and oxides of nitrogen (Beauchemin and Tampier, 2008).

When the olive pits are combusted a similar variety of particulate matter and gases are released. Particulates range in size from .125-6 microns in diameter and 30% of these particles are $PM_{2.5}$ and small enough to penetrate deep into human lungs and cause long lasting respiratory problems (Strofylas). The gases olive pit combustion produces can include carbon dioxide, sulfur dioxide, water, and nitrogen (Beauchemin and Tampier, 2008).

2.3.3 Emissions from Natural Gas Kilns for Ceramics

The heavy pollutants produced by wood-fired kilns have prompted the Moroccan government to consider natural gas an alternative. Natural gas is a fuel composed of methane, ethane, propane, butane, and various inert gases like nitrogen, carbon dioxide, and helium. Methane is the largest part of the mixture, at about 85% of the composition of natural gas. The emissions from natural gas-fired kilns include “nitrogen oxides (NO_X), carbon monoxide (CO), and carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), volatile organic compounds (VOCs), trace amounts of sulfur dioxide (SO_2), and particulate matter (PM)” (EPA). NO_X is an unavoidable pollutant that results from the combustion of methane, but other compounds like CO can be minimized through proper tuning of the kiln. The main exhaust produced by natural gas combustion is CO_2, classified as a major factor in climate change by the EPA. However, because of the heavy metals and particulate matter produced by the combustion of wood, natural gas is considered a much cleaner fuel source.

2.4 Alternate Methods of Pollution Control

One alternate means of pollution control would be to modify traditional kilns so that they produce less pollution. This modification is cheaper and easier than switching to gas for artisans, as they could maintain the use of traditional production methods while still cutting down on pollutants. This proposed modification would entail the addition of pollution control devices to existing kiln infrastructure. The EPA recommends five devices for cleaning particulates from exhaust (EPA, 2010):

1. Electrostatic Precipitators
2. Fabric Filters
3. Venturi Scrubbers
4. Settling Chambers
5. Cyclones

A sixth very promising solution was found while doing research on previous methods to reduce pollution from gas kilns:

6. Catalytic Converters

This section will outline how each of these devices works, and their respective advantages and disadvantages.

2.4.1 Electrostatic Precipitator (ESP)

Electrostatic Precipitators use electrostatic force to remove particulates from the air. The precipitator consists of collecting plates, discharge electrodes, rappers, and hoppers. When dirty air enters the precipitator, it passes by the discharge electrodes. These electrodes negatively charge the passing pollution particles. Next, the air passes the collecting plates. These plates are embedded with positively charged electrodes, which attract the negatively charged particles. After passing the plates the air has had 99% of the particulates cleaned from it and is released. To clean the device itself, there are rappers. When the power is off, the rappers are released from above the collecting plates brushing the particulates off the plates.

The particulates fall to the hopper in the bottom of the device where they can be removed before the next use (*How an Electrostatic Precipitator Works*).

Electrostatic Precipitators work best when the air flows between 3.5 and 5.5 feet per second due to there being a more even distribution of particles between those speeds. Precipitators also work best when the particles are mostly larger than 0.4 micrometer. Particles that are smaller than 0.4 micrometers are difficult to collect because the charge diffuses faster. A major concern when using precipitator is the electric resistance of the particles. The higher the resistance, the more difficult it is to remove. For example, sulfur increases the resistance of surrounding particles reducing the precipitator's efficiency, but sodium or iron oxides decrease resistance increasing efficiency (*Electrostatic Precipitator Knowledge Base*).

The EPA estimates that a general electrostatic precipitator would cost $800,000 to buy and install. Additionally, the EPA estimates that it would cost an additional $200,000 per year to operate and maintain an electrostatic precipitator (Coy, Greiner, et al 1999).

2.4.2 Fabric Filters/Baghouse

Fabric filters, or baghouses, clean exhaust by forcing the exhaust through layers of fabric filters. Baghouses became feasible in the 1970s when high thermal resistant fabrics were invented. Using fabric to clean exhaust allows the device to limit the amount of moving parts to only an input fan. This fan pulls air into the enclosure housing the filters. The air rises and large particles fall out. Smaller particles are removed as the air filters through the layers of fabric. While there are many different baghouse designs, they all follow this general principle (*Baghouse / Fabric Filter*).

Baghouses are extremely efficient for particles of any size. The efficiency varies between 99-99.9% depending on the gas velocity and cleanliness of the device. Fabric filters are extremely useful as a secondary or pre-cleaning device. They can be used in conjunction with electrostatic precipitators to remove finer particles or more resistant particles (*Baghouse / Fabric Filter*).

While baghouses are easy to use and are highly efficient even when operating conditions change, there are disadvantages. The main disadvantage is caring for the fabric filters. Fabric filters can wear extremely quickly depending on gas characteristics such as temperature and composition. More resistant fabrics are expensive and the cheaper fabrics are susceptible to fire if the operating temperature exceeds nominal conditions. Heavy metal or acidic particles are more corrosive than regular carbon based particles and can wear down the fabric's cleaning layers. The air flow must also be dry to ensure that wet particles do not clog the fabric filters. These disadvantages mean that the filters must be replaced periodically to ensure high efficiency (*Air Pollution Control Technology Fact Sheet – Fabric Filter*).

The EPA estimates that a baghouse would cost between $13,000 and $55,000 per cubic meter per second depending on the quality of the fabric and size needed. Annual operation and maintenance would cost $13,000-83,000 per cubic meter per second (*Air Pollution Control Technology Fact Sheet – Fabric Filter*).

2.4.3 Venturi Scrubber

Venturi scrubbers use water to clean polluting exhaust. Dirty gas enters a cyclone separator at a high speed where it is met by a spray of water. The diffused water droplets absorb the particulates upon collision. The water then drops out of the bottom of the separator into a tank where it can be filtered and reused. The clean air exits the top of the separator. The venturi scrubber has efficiency up to 99%. However, this efficiency is based on power consumption and particle size. The scrubber works very well when the particles are larger than 1.0 microns. If the particles are any smaller, the necessary power to increase the water pressure is extremely high. The scrubber cannot collect particles smaller than 0.5 microns (*Air Pollution Control Technology Fact Sheet – Venturi Scrubber*).

One of the benefits of a venturi scrubber is that they are effective under almost any operating conditions. Since the scrubbers use water, there is no concern for gas temperature and the scrubber can operate under any gas flow rate and dispersion. The main benefit of the venturi scrubber is its ability to collect gaseous pollutants using absorption with an effective removal rate of 70-90%, in addition to removing 99% of particulate pollution. The use of water makes the venturi scrubber stand out from other pollutant collectors in that the water allows it to collect gaseous pollutants that would be released in incomplete combustion of wood. However, venturi scrubbers have a few disadvantages. One of these is the use of water. When in the scrubber, the water can corrode the sides especially at high pressure. Also, the scrubber creates wastewater in the form of sludge. Care must be taken to ensure that this wastewater is filtered and not allowed to seep into the local water tables (*Wet Scrubbers*). This sludge can also be recycled back into the scrubber, using evaporative methods to separate the trapped particles from the water. This resulting enriched fly ash can be disposed of in a much safer manner than the sludge. The water can then be reused in the scrubber.

A venturi scrubber would cost between $58,000 and $120,000 depending on the flow rate and an additional $9300-254,000 per cubic meter per second per year to maintain and operate according to the EPA (*Air Pollution Control Technology Fact Sheet – Venturi Scrubber*). The high end of that price range includes the use of venturi scrubbers in extremely demanding situations, such as smelting. Wood kilns burn at much lower heat with fractions of the airspeed of smelting, so this application would be on the extreme low end of that quoted price range.

2.4.4 Settling Chamber

Settling Chambers are by far the simplest means of cleaning exhaust. A settling chamber consists of a large metal chamber and a collection hopper. Dirty air enters one side of the chamber and is allowed to expand inside of it. Clean air then exits the other side. The particles fall from the air into the collection hopper due to gravity. The efficiency of a settling chamber is dependent on the time spent in the chamber and the size of the chamber. Theoretically, settling chambers are 100% efficient in an extremely large chamber. However, due to efficiency relying on size, settling chambers are large and not scalable for some operations. The advantage of settling chambers is their simplicity. There are no moving parts, low energy costs, and they are easy to operate and maintain (*Control of Particulate Matter Emissions*).

The EPA estimates that a settling chamber costs between $330 and $10,900 per cubic meter per second depending on size and design. Annually, the operating and maintenance costs would be between $13 and $470 per cubic meter per second (*Control of Particulate Matter Emissions*).

2.4.5 Centrifugal Separator (Cyclones)

Centrifugal separators are also very simple. Centrifugal separators offer a low maintenance and easy way to clean exhaust by utilizing inertia separation. They consist of an outlet tube, cylinder, and a collection hopper. Dirty air enters the top of the cylinder at a high velocity starting a cyclone in the cylinder. The particulates are spun along the walls of the cylinder through the force of air pressure and fall into the collection hopper at the bottom. This creates clean air in the center where the outlet tube is located and it allows the clean air to escape (Camfil Farr, 2011(B)).

Centrifugal separators are 95-98% efficient for large particles depending on multiple factors. One particularly useful factor is that the efficiency increases as the size of the cylinder decreases. This allows the separators to be scaled down and placed in parallel. Centrifugal separators can handle gas with any characteristics, but work best with lower density gases. The only moving part is a fan to pull or push air into the cylinder and there are no filters to clean or replace. The major disadvantage is that separator cannot remove small particles. Therefore, they are often combined with water cleaning methods like those in a venturi scrubber or fabric filters like a baghouse (Camfil Farr, 2011(A)).

Centrifugal separators cost between $17,700 and $38,100 per cubic meter per second. Since there are relatively few moving parts, the maintenance and operating costs would be low. If a fabric filter was attached, the costs would be significantly higher (*Dust Collector Cost*, 2003).

2.4.6 Catalytic Converter

We researched a sixth idea with inspiration from a project by Brett Stern in association with Alfred University in 2003. Stern used a catalytic converter in a wood fired ceramic kiln. A catalytic converter is a honeycomb shaped device that helps complete the combustion of exhaust, destroying hydrocarbons, carbon monoxide and nitrogen oxides ("What is a catalytic converter and how does it work?", 2000). While generally used to clean the exhaust of vehicles, Brett Stern's research shows that a catalytic converter is applicable for use in a kiln. In tests, the kiln was run for seven hours and reduced pollution by 70-90%, and the color of the exhaust was much clearer (Stern, 2003).

Catalytic converters are very easy to use and maintain. They have no moving parts as they are only a wire mesh and in some cases a burner is added to get the converter up to temperature. The converter would have to be cleaned between uses of the kilns. If the converter becomes too covered in soot and ash the effectiveness drops. It could also be used with any of the methods described above (Stern, 2003).

A catalytic converter would cost $2400-4000 and the burner and mounting system would only cost an additional $200. However, there are more complex systems that could be utilized that involve preheating and fans. These systems would cost more and would be designed for the specific application (Stern, 2003).

Morocco's global awareness has led to an increased concern for global climate change and the effects of air pollution. Morocco has realized its great susceptibility to global climate change, the fact that it is facing severe water shortages and desertification, and has taken action to minimize further deterioration in climatic conditions. One of these proposed methods is switching from traditional kilns to natural gas kilns. Due to the reduction in polluting particulate matter emissions gained by a switch to natural gas, it may at first seem obvious to make the change. However, further research has indicated that gas kilns fall short in other areas, especially concerning the quality of the zillij they produce. Because of this, our project has extended our research into alternate means of pollution control, with the priority of preserving traditional zillij manufacturing processes as much as possible.

3. Methodology

This section covers the design of our project, data sources, measures we used for analysis, and the procedures that led us to our final recommendation.

3.1 Design

One of the main concerns for all artisans transitioning to new methods of zillij tile production is cost, both capital and annual. Therefore, we used a cost benefit analysis to determine the advantages and disadvantages of natural gas kilns and traditional kilns with a scrubber attached. After this cost benefit analysis, we focused on scrubbers as the most promising potential alternative.

A cost/benefit analysis uses real costs and externalities, a cost that a third party incurs, to develop a comparison between different solutions. Once set up, the cost/benefit analysis can provide the data needed to determine if the most effective scrubber is more cost efficient than natural gas kilns.

3.2 Data Sources

We conducted a literature review to find sources about air pollution controls and the environmental effects of burning gas and wood. We used internet search engines such as Google and WPI Summons. We prioritized results that were related to Morocco and Moroccan artisans. A lot of these sources were from aid organizations like the Millennium Challenge Fund. To find data on pollution prevention methods, we relied heavily on the United States' Environmental Protection Agency. The EPA is very vocal about preventing pollution and has done extensive research on preventative methods, including cost analyses upon which we base our own conclusions. They have done cost analyses for these device that we are basing our analyses on. Other sources for pollution prevention devices included manufactures and scientific projects.

Our main source of information about traditional kilns was Arabesque Inc., a Moroccan zillij company based in Fes with projects throughout the United States and Europe. Our main contact at Arabesque Inc. was Reda Naji, who manages the operations in Fes. We interviewed Reda extensively for this project. Arabesque Inc. is a family company and Reda has been heavily involved in everyday management. He was able to answer all of our questions and demonstrate how zillij is made. He showed us the workshop and the kilns. We also met and interviewed Reda's cousin, who oversees the operation of the kilns and was able to demonstrate how tiles are made and show us the gas kilns that the Moroccan government purchased for experimentation. These interviews served to identify the base cost of traditional kilns and the current natural gas kilns. Also, he pointed out to us the air pollution created by the 240 kilns in the Fes region (see appendix B, C and D for more detailed information about how we conducted our interviews).

3.3 Measures

In order to evaluate the several unique factors involved in our analysis our team needed to establish a measuring standard. We chose to use currency, specifically US dollars. Even though some of our figures were not originally US dollars, a standard conversion factor could be utilized to convert all numerical currency data to US dollars. Studies have also been done to establish the US dollar cost to the environment and to human health resulting from air pollution in several specific cases.

The costs that we measured where: capital cost, operating cost, and maintenance cost. The capital cost is the cost of buying and installing the option. The operating cost includes costs such as energy requirement and any extra costs like waste disposal. The maintenance cost is any cost that involves the upkeep of the scrubber or natural gas kiln.

3.4 Procedures

The monetizing of installation and maintenance costs is relatively easy for both natural gas kilns and scrubbers because the figures that we found in our research or supplied by the producers of the kiln or scrubber are already in US dollars or euros. Our team took the installation costs and multiplied them by the number of necessary devices per kiln in the Fes region to find the economic cost realized by the artisans. The initial cost will most likely be subsidized, if not covered, by the Millennium Challenge compact. Therefore, the most relevant cost to artisans was the operation and maintenance costs. These costs were adjusted to reflect the price per firing of each type of kiln to show the difference in costs between each option.

The monetizing of the environmental benefits involved some crucial estimations by our team. Our team focused specifically on the effects of smog in the region as it is the most direct effect from the kilns on the population. There is undisputed evidence that smog, otherwise known as low atmospheric ozone, can cause damage to humans and the regional agricultural economy (Su). Studies were already conducted that established the agricultural and health care cost savings in the United States after the clean air act was passed. We used these studies and the ratio of the population of the United States to the population of Morocco to estimate the monetary savings from significantly reducing smog levels in the region.

The two hardest monetary conversions were estimates involving greenhouse gas emissions and worth of preserving the cultural integrity of the zillij industry. After looking at the initial goal of the government, it seemed that the main objective was to remove the particulate matter from the exhaust stream of the kilns. Both options that we propose will remove close to all of these particulates from the exhaust stream leaving only the greenhouse gases produced and the tile quality to be evaluated in our cost analysis. Our team looked at the composition of the exhaust gases released by each option from our research on combustion and compared this to the cost. Then we compared tiles fired traditionally to similar tiles fired in gas kilns and interviewed the participants to find out how different quality as judged by artisanal experts affects the aesthetic worth of the zillij that is produced. The cultural integrity of tiles produced was assessed on how true they are to traditional tiles and whether they can actually be used in zillij products. Using the data we gathered, our team compared the pros and cons of each option to recommend the best solution for the artisans in Fes.

4. Findings and Analysis

The goal of our project is to preserve traditional methods of zillij production while effecting a reduction in harmful emissions. The preservation of traditional methods for zillij production is important to both maintain the livelihoods of the artisans involved in zillij production and to retain the cultural significance and aesthetic quality of their work. Through observation, interviews, and scholarly research we have come to a working understanding of the state of zillij production in Morocco. From our research, we have established a number of possible solutions to the problem that zillij producers face. These solutions range from the modification of gas kilns to the installation of scrubbers and other alternate means of pollution control.

4.1 Gas Kilns

Despite the environmental advantages of gas fired kilns, the ones that the Moroccan government proposes to install are not an adequate solution. In fact, in practical use, we have found that the proposed gas kilns are an incomplete alternative to wood fired kilns. Tiles fired in a gas kiln have an extremely high failure rate compared to tiles fired using wood kilns, and the traditional glazes that artisans use do not produce the right color or finish when fired in a gas kiln. According to the foreman at the zillij factory we visited, the nominal failure rate for tiles fired in a wood burning kiln is 3%-5%. In a gas fired kiln, the failure rate is 85%-90%. A gas fired kiln will produce a few usable tiles distributed randomly about the kiln, but the vast majority of the tiles produced are unsuitable for the production of zillij: They are much too brittle, and shatter when artisans attempt the delicate process of shaping them into zillij tile.

It is difficult to say the specific reason that the proposed gas kilns do not work without extensive research and experimentation that is beyond the scope of our project. There are, however, some obvious differences between the firing environments of each kiln that could conceivably contribute to a higher failure rate in the proposed gas ovens. While explanation of the failure of the gas kilns to produce quality zillij is not the focus of this project, we would like to offer some conjectures about the possible reasons for the failures. The first and likely most important difference between the kilns is a lack of airflow in the gas kilns. The wood burning kilns are heavily ventilated, allowing air to flow in and around the tiles as they bake. The gas kilns, on the other hand, have very limited airflow. It is possible, even likely in our opinion, that ambient atmospheric gasses contribute to the proper solidification of clay into tile. Another major difference between the two kilns is an utter lack of smoke in the gas fired kilns. This lack of smoke is one of the environmental advantages of natural gas, but it is possible that the dense "smoke bath" that tiles receive as they are fired is integral to the process of producing a successful tile.

Another side effect of the lack of airflow occurs with the glazes used in second firing of the tiles. Arabesque, like many other zillij companies, uses glazes on their tiles whose recipes date back to the Middle Ages. Arabesque's glazes rely on the oxidization of natural compounds like iron and chrome to produce the desired colors. In gas ovens, almost all of the oxygen is burned off in the combustion process with natural gas, leaving the inside of the kiln very low in O_2. Because of this, gas ovens are unable to be used to fire tiles glazed with traditional methods, as the materials in the glaze do not oxidize and therefore do not produce the right colors.

Some gas kilns had already been acquired for testing purposes when we went to observe the factories. These kilns were being utilized, but in a very specific and limited fashion. The owners of these gas kilns would purchase already-fired tiles in bulk from people who had wood fired kilns, and then apply modern glaze to the tile and use their gas kilns to finish this modern glaze. Modern glazes are very vibrantly colored, and the tiles produced look very distinct from those produced with traditional glazes. The major problem with the modern glazes available to zillij producers is durability. The glaze simply does not hold up under the same number of day/night rain/sun cycles that traditional glazes can handle. In fact, the modern glazes in use stay vibrant for only 8-16 months when exposed to the elements. Contrast that with traditional glazes, which have endured for centuries under extremely harsh conditions (see figure 17)

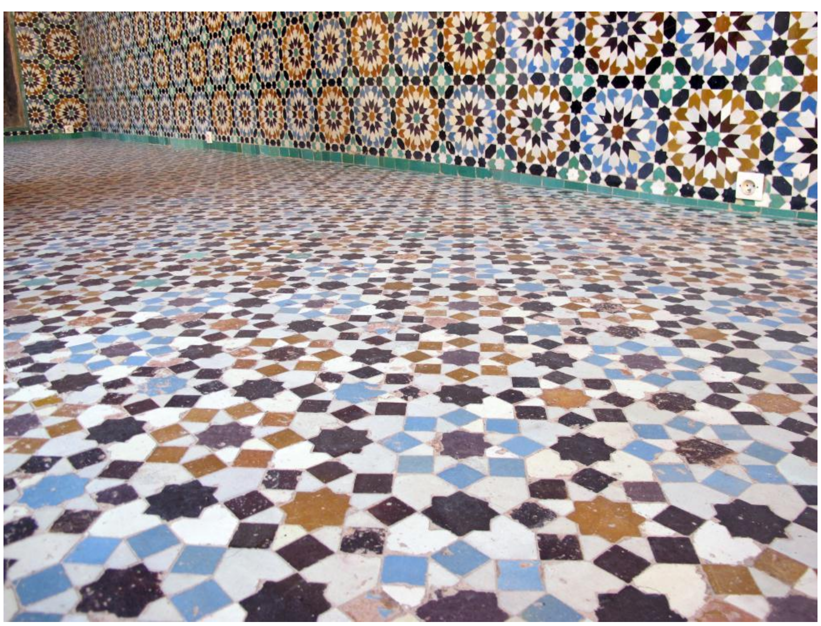


Figure 17: 400 year old zillij at a Ben Youssef Madrassa in Marrakesh

In addition to the aesthetic cost, there is a social cost to the use of the proposed gas kilns—to utilize this new technology, artisans will have to abandon traditional methods of zillij manufacturing as well as abandon the high standards that have made Moroccan zillij world-renowned. Switching to the proposed gas kilns would result in the artisans throwing out eight of every ten tiles they make; making tiles would become a costly and inefficient process. The artisans would then have to make compromises in the finish of their tiles, forced to use modern glazes that don't have the same permanence as traditional methods. This is an unacceptable situation for anyone concerned with the future of artisans, preserving artisanal talent, and enhancing the artisanal economy of Morocco as a whole.

The proposed gas kilns are clearly lacking in many necessary attributes to make high quality zillij, but it is potentially possible to change their design to increase their success rate. As stated above, the biggest difference between traditional wood fired kilns and the proposed gas kiln is airflow. Additional fans could be added to gas kilns to force air through the firing chamber, providing a more oxygenated environment for the tiles to bake in. This could potentially cause the failure rate of the first firing of tiles to drop to acceptable levels, while allowing traditional glazes in the second firing of tiles to oxidize correctly. With this design, gas kilns would still produce much less particulate pollutants than wood fired kilns, while allowing artisans to retain traditional methods and standards of quality.

Modifying gas kilns is unfortunately not without its own set of drawbacks. Gas kilns are designed to be as efficient as possible; they are heavily insulated and have minimal airflow to conserve heat as much as possible. The biggest cost in a gas kiln is heating the air to heat the tiles. Current gas kilns are designed with low airflow to maximize fuel efficiency. The less air that needs to be heated, less gas needs to be used, and the cheaper the process is. For gas kilns to work there would need to be considerably more airflow through the kiln. As the volume of air that needs to be heated grows, so too does the cost of running the kiln. Proper airflow will require an increase in heated volume of air to match the airflow of a wood fired kiln, driving the cost up significantly. Compared to the cost of a wood kiln, even an oxygenated gas kiln could be infeasible due to cost. Wood kilns have their own set of drawbacks however, including the potential for massive environmental cost.

4.2 Pollution and Morocco's Economy

Morocco's zillij industry produces numerous economic advantages, but if pollution costs are taken into account because of deficiencies in traditional methods, it can be argued that the total economic cost of zillij production outweighs its economic benefits. The Moroccan government is forcing zillij producers to come to terms with both the social and environmental cost of producing zillij in hopes of creating a progressive environmental change in the industry. Currently zillij production involves the firing of clay tiles in kilns fueled by scrap wood and olive pits. These materials are cheaper than other fuel sources but produce large amounts of soot, thick black smoke, and many poisonous and greenhouse gases. For this reason the manufacturing of zillij is carried out in a valley outside of Fez to improve city air quality and isolate the smog in the valley. Soon steps will be carried out to push zillij production even farther from Fez (Reda 2012).

The decision to relocate the kilns has made life more challenging for those working on them, but the rationale behind the government's decision to relocate the kilns can be understood through a number of socioeconomic factors. The direct monetary cost to run a wood fired kiln for a day is around $45 USD per firing. However, the social cost of the pollution generated is much harder to calculate and is not directly felt by the companies running the kilns. The black smoke generated by wood fired kilns is composed of particulates and a variety of greenhouse emissions. The particulate matter and gases released in the combustion of wood and olive pits creates smog, which can linger in the area for long periods of time after the kilns are finished firing. Smog causes several short term medical complications including, “coughing, sneezing, headaches, tiredness, irritation, nausea, and hoarseness of the throat, nose, and eyes, and constrictions of the chest” (Su). Prolonged exposure can cause long term ailments including increased susceptibility to respiratory illness, fibrosis, premature ageing, respiratory cancers, and death (Su). To combat these health problems and to minimize global climate change, the Moroccan government has begun working towards regulations similar to the Clean Air Act in the United States.

The economic cost savings from smog reduction in the United States due to the Clean Air Act was around $118 billion in 2010, derived through savings in health care and agricultural industry (Su). Using the ratio of the Moroccan population, 32,272,974 people, to the population of the United States, 311,591,917 people, it can be estimated that a savings of around $12.2 billion would be experienced in the Moroccan economy over the next few decades by reducing smog to comply with the Clean Air Act. (Su, CIA World Fact Book) The greenhouse effects of nitrogen oxide, CO, CO_2, volatile organic compounds, and sulfur oxides contribute heavily to global climate change (Beauchemin and Tampier). Climate change has long term costs that are orders of magnitude harder to monetize than the costs of smog but are equally as important.

The reason the Moroccan government has implemented the current legislation restricting zillij production is to continue these environmental reforms.

The economic cost and benefits of each proposed solution must be analyzed in order to measure its potential effectiveness. Moving to natural gas fired kilns would significantly reduce particulate matter emissions (EPA). Natural gas fired kilns also cost around 80,000 euros ($103,120), which scaled up to all 240 kilns in Fes would mean an initial cost of 19.2 million euros ($24.7 million). Since these kilns would use natural gas at a cost of $65 per each firing, which occurs once every other day, the operating cost would be $2.85 million annually (Roughly a $1.7 million cost increase over wood fired kilns per year). It is worth noting that the given cost of $65 per firing applies only to the proposed gas kilns, which have proven to be ineffective. It is likely that natural gas kilns modified to actually produce quality zillij tile would use several times as much fuel. This annual operating cost also does not include maintenance, repairs, or the fact that the foreign sourced natural gas has volatile prices.

Despite the obvious and easy to acquire environmental advantages of natural gas, it is unlikely that gas fired kilns are a good solution for the unique situation of Morocco's zillij industry. According to our findings, applying pollution control to wood fired kilns would provide almost the same environmental benefit while preserving the quality and history of traditional methods.

5. Conclusions and Recommendations

Our recommendation for a system of pollution reduction is the attachment of a venturi scrubber to a traditional wood-fired kiln. This would preserve the cultural heritage of zillij artisans and traditional methods of zillij production, while still eliminating harmful pollutants.

Venturi scrubbers offer the best balance between efficiency and cost within the operating parameters of zillij manufacturing. Traditional wood-fired kilns produce both particulate matter and gaseous pollutants. For these conditions, venturi scrubbers are very efficient. For particulate matter between $PM_{2.5}$ and PM_{10}, venturi scrubbers are between 70-99% efficient with nominal power consumption (see figure 18) (*Wet Scrubber Application Guide*, 1998).

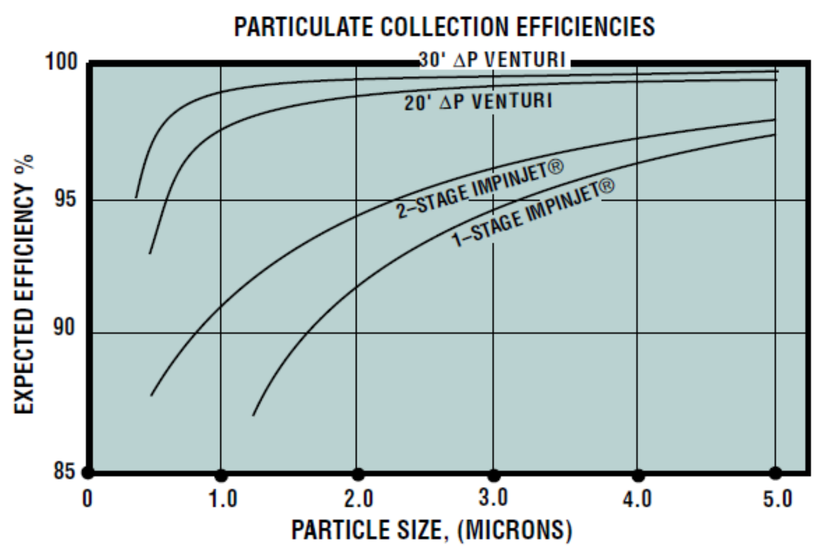


Figure 18: Particulate collection efficiencies for venturi scrubbers based on particle size

As shown by the graph above, depending on the style of venturi scrubbers, the scrubber can achieve an efficiency of as high as 95% for particles with a diameter of 0.5 microns. These particles are the most dangerous and are the most important to remove. Venturi scrubbers are generally used in situations where the majority of particles are $PM_{2.5}$ and high removal efficiency is needed, as is the case for traditional wood-fired kilns. For larger particles around the size of 5.0-10.0 microns, the venturi scrubber, depending on the style, can achieve an efficiency nearing 100%. Additionally, these efficiencies could be increased with an increase in power consumption (*Wet Scrubber Application Guide*, 1998).

Venturi scrubbers also offer a unique advantage because they can collect water soluble gases like those created when wood is burnt. Wood releases oxides of nitrogen and sulfur, carbon dioxide, and carbon monoxide. These gases are all water soluble and would be able to be removed with a venturi scrubber depending on water temperature and throughput (see figures 19 and 20) ("Solubility of Gases in Water").

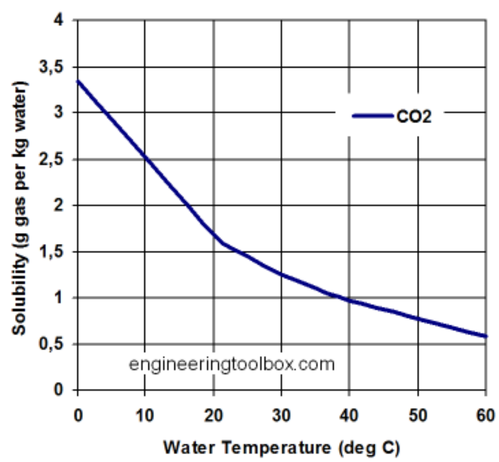


Figure 19: Solubility of carbon dioxide in water by temperature.

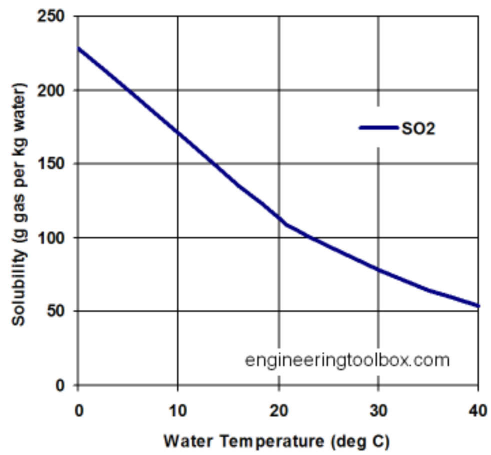


Figure 20: Solubility of sulfur dioxide in water by temperature.

These graphs show the water solubility (g of gas/kg of water) of carbon dioxide and sulfur dioxide, two gaseous pollutants released from traditional kilns, depending on water temperature. The graphs show just how soluble these gases are, and imply that they would be very easily removed with a venturi scrubber ("Solubility of Gases in Water").

The cost of a venturi scrubber makes it a good replacement to natural gas kilns. Natural gas kilns cost about $103,120 and cost $20 more per firing than traditional wood-fired kilns. Venturi scrubbers are much cheaper than natural gas kilns. The capital cost of a venturi scrubber is around $60,000 in this application. For operating expenses, it uses 0.7 – 7.0 kWh of electricity per 1000 m^3 of exhaust ("Venturi Scrubber," 2012). EMIS (Energy and the Environment and Information for the Flemish Region) did two case studies of venturi scrubbers in the chemical sector to determine their costs. In the first case study, done in 2004, a venturi scrubber was used to remove dust and organic compounds. The flow rate of the gas was 10,000 Nm^3/h (normal meters cubed per hour, a unit used to measure unpressurized gas flow rate) and the gas was around room temperature. The adjusted capital cost of the scrubber was about

$77,000. The operating expense was about $12,000 per year. The second case study was done in 2004 and was tested on gas more similar to that leaving a kiln. The flow rate was 7,000 Nm^3/h and the gas was at a temperature of a maximum of 110˚C. The adjusted capital cost was about $82,000 and the adjusted operating expense was about $5200 per year ("Venturi Scrubber," 2012).

It is worth noting that the expected gas flow rate and temperature of zillij kilns is similar to that in Case Study 2, though we are expecting a slightly lower flow rate and slightly higher operating temperature. Another very important point is that for every two wood fired kilns, we only need one scrubber as kilns fire only on alternate days.

If we apply the data from these case studies to the possible instillation of these scrubbers on traditional kilns, there is a large saving in capital costs and possibly a saving in operating expenses:

	Capital cost per kiln	Capital cost to replace 240 kilns	Additional operating expense per firing	Additional yearly operating expense per kiln including fuel and maintenance	Estimated 5 year cost including installation, maintenance, and fuel for all 240 kilns
Natural Gas Kiln	$100,000	$24,000,000	$20	$7,300	$25,752,000
Case Study 1	$77,000	$9,240,000	$33	$12,045	$12,130,800
Case Study 2	$82,000	$9,840,000	$15	$5,475	$11,154,000

As is shown in the table above, both Case Study 1 and Case Study 2 indicate a cost savings over gas for both initial and 5 year costs, including fuel and maintenance.

The capital costs associated with installing venturi scrubbers could be offset by local venturi scrubber production. As venturi scrubbers are very simple machines, local production would drive the installation and maintenance costs down significantly. Local production would guarantee the availability of skilled mechanics and maintenance workers for the scrubbers, as well as generate jobs and stimulate the economy of Fes. Scrubber production in Fes could even potentially allow scrubbers to be applied to other polluting industries in Fes, further reducing air pollution.

With every solution there are always some additional concerns. For venturi scrubbers, the biggest difficulties are instillation and waste water disposal. The installation of a venturi scrubber does not consist of simply placing the scrubber on top of the kiln. Ducting will be added to ensure that water does not leak into the kiln. The ducting must not inhibit air flow through the kiln as this can cause issues like those in the natural gas kilns, such as low oxygen levels in the firing area. This solution would have to be achieved through adding a fan of some sort on the outtake of the scrubber, a marginal additional cost. This ducting must also attach to two kilns, as kilns are fired on alternate days (see figures 21 and 22, and appendixes G and H for more detailed scrubber schematics and additional renderings). Venturi scrubbers also produce waste water especially when used on the exhaust from wood burning. This water contains gases that could damage water sources and needs to be disposed of properly and treated. These disadvantages do not outweigh the advantages as venturi scrubbers are highly efficient, can remove water soluble gases, and are easy to operate and maintain ("Venturi Scrubber," 2012).

Figure 21: A rendering of the proposed scrubber installed on two kilns.

Figure 22: A rendering of the ducting connecting the scrubber to the two kilns.

Following this recommendation would allow Moroccan artisans to continue using traditional methods to make zillij, while addressing the problem of air pollution and climate change. The skills of zillij artisans have been handed down generation by generation, a slow evolution through nearly a millennia of refinement. To suddenly disrupt this with gas powered stoves and synthetic glazes would do an extreme disservice to the rich heritage of Morocco's handicraft industry. Zillij artisans rely on delicate traditional methods to produce their extraordinarily beautiful and durable mosaics, and the high aesthetic standards of Moroccan zillij will be preserved through the use of our recommendation.

Appendices

Our appendices contain research we have done that does not directly apply to our project, but could be useful for future project teams dealing with other issues facing zillij artisans or the Moroccan handicraft market in general. Our appendices also contain detailed information that does not fit into the background, but they support material in several chapters.

Appendix A: The History of Moroccan Tile

Zillij is the arrangement of terra cotta tiles covered with enamel into geometric patterns (Rhodes, Fred 2002). These are used to decorate both the interior and exterior of buildings, as well as serve as an ornament on furniture and in fountains (figure 23).

Figure 23: Intricate zillij on the base of a fountain.

Zillij has its roots dating back to the 8th century, when the Moors conquered Spain (Rhodes, Fred 2002). The Moorish people brought with them a number of pottery techniques that were adapted by the Spanish to produce ceramics (the style is known as Hispano-Moresque ware) such as tableware, platters, and vases (Rhodes, Fred 2002). By the 10th century these techniques had found their way back to Morocco, and the Moroccans began using them to produce tiles for mosaics. At that point, the palette of colors utilized was very limited, but the production techniques were already refined. The only colors available to the artisans at that point were white and brown (Rhodes, Fred 2002). Artisans produced the individual tiles using a hammer and a chisel, utilizing a radius gauge to perform the precise measurements required to create geometrically perfect mosaics. Each tile is painted and covered in enamel after being cut, and then they are fit together like a giant puzzle to form the final mosaic. Despite the time, effort, and training required to produce just one tile, this same process is still in use today by Moroccan artisans (Rhodes, Fred 2002).

In the 14th century, under the Merinid dynasty, zillij grew dramatically in popularity (Rhodes, Fred 2002). The rise in popularity of zillij can be attributed directly to the teachings of Islam. Islam prohibits the worship of idols or images, so mosques cannot be decorated with depictions of religious scenes or figures (The Holy Qur'an 1983). Mosques instead are decorated with intricate geometric zillij (figure 24), meant to reflect the beauty of Islam without going against its teachings.

Figure 24: An example of precisely fitted geometric zillij.

By the 17th century, the artisans in Fes and Meknes were working with much more vibrant colors, such as red, yellow, green, and blue (Rhodes). This allowed artisans to produce even more complex patterns. Zillij was not confined to use in palaces and mosques anymore; at this point it began being extensively used in interior and exterior decoration of private homes as well. With a wealth of patrons, the art of zillij flourished and continues to flourish today. However, by the end of the nineteenth century artisan guilds had all but disappeared (Faroqhi, Suraiya 2009). Artisans, particularly artisans who are unaffiliated with a company, do not have the same socio-economic power they once did, and artisans are facing more and more challenges to their way of life.

Appendix B: Interview Guide for Artisans

The goal of the artisan interviews was to broaden our data to include the success factors of all Moroccan artisans. We started with general questions to gain background information about the artisan, such as types and styles of products and procedures. After this, we narrowed in on the artisan's production methods and possible problems or benefits. This gave us insight into the problems that artisans face and success factors. We hoped to interview many different types of artisans including those that work with tiles, textiles, wood carvings, and metal. For small-scale artisans, we focused on rural artisans that are self-employed and for large-scale artisans, we focused on artisan cooperatives and larger companies like Arabesque. Our questions included:

a. What are your main products?

b. How do you produce these goods?

c. Where do you sell these goods?

d. How successful are you in your market?

e. Have any products been more successful or less successful than others?

These questions were the basic objectives of the interview. However, we in no way held ourselves to these questions because open-ended questions often resulted in greater depth of answers.

Appendix C: Islamic Art Specialists

Islamic art specialists were very important to interview. They served to identify qualities that make Islamic art popular and culturally meaningful.

Possible questions include:

a. How well known and world renown is zillij?

b. How popular is Islamic art?

c. What makes Islamic art special and different?

d. What qualities do consumers desire in Islamic art?

e. What qualities do consumers try to avoid?

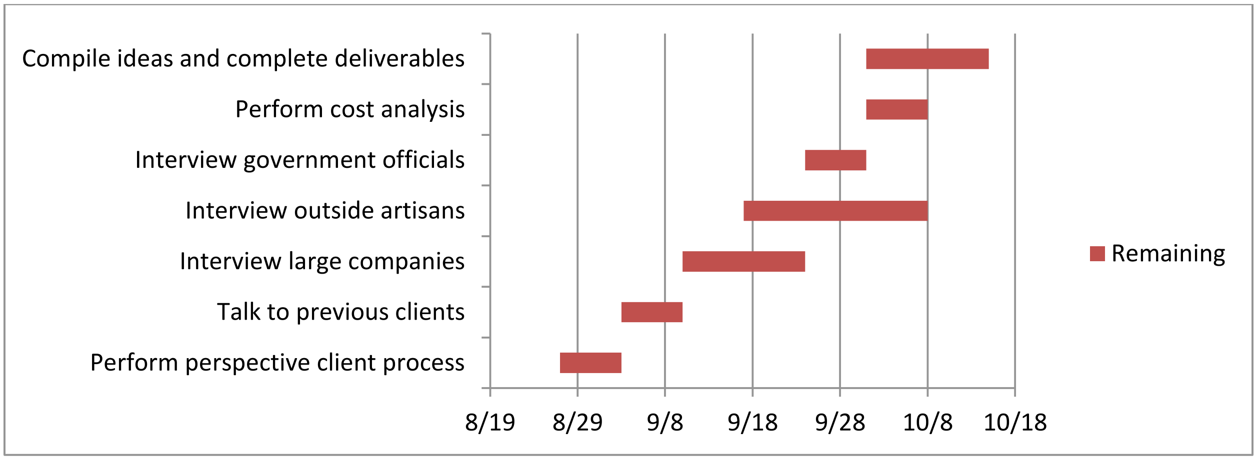
f. How has Islamic art evolved and expanded?

Appendix D: Interview Introduction

This introduction will be the basis for introducing ourselves before interviews.

As-Salamu Alaykum. We are George Gettel, Stephen Oliveira, and Micah Flock. We are completing our Interactive Qualifying Project necessary for graduation from Worcester Polytechnic Institute in Massachusetts, USA in conjunction with Al Akhawayn University in Ifrane. Our research compares artisans of different sizes and the goods they create. We were hoping you could take some time out of your day in order for us to interview you about your art and production methods.

Appendix E: Gantt Chart



Appendix F: Walid's Analysis on the Documents He Researched in French and Arabic

Morocco is Engaged in more than 60 international agreement Aware of the environmental hazards on the planet in order to search for solutions a guarantor for a healthy environment, taking into account the fragile situation of Morocco before the phenomenon of climate change, both on the stocks of water, soil, beaches Otherute fish, Fbahtdana Seventh Meeting of the Parties COP7 demonstrate its solidarity with the international community towards climate variability and in accordance with the principle:

Shared responsibility among all nations,

This solidarity was present through all the vertices of Rio to the Rio +5, as well as the intensive presence of Morocco in all meetings devoted to the preservation of the environment and sustainable development

Morocco is part of the continent of Africa, which is the most fragile continent as a result of climate change, bringing together experts on its weakness in terms of reducing water pollution, desertification, loss cover forest cover, flooding and deadly epidemics.

Among the agreements signed by Morocco, the Convention on the United Nations Framework on Climate Change and during the Summit of the United Nations on Environment and Development in Rio de Janeiro (Brazil in June 1992) and ratified in December 1995. Defined in Article IV of this Convention obligations of the signatory States in 10 paragraphs, each one of interest to specific activities linked to climate change.

The development in Morocco remain hostage to climatic conditions and water resources by virtue of geographical location, which is characterized by, (which includes parts of arid and semi-arid), and by virtue of the political choices (given the initial development of the agricultural sector.

However, the results of recent studies raise the alarm about the potential impacts of climate change and its consequences of severe high temperatures, and the volatility system outfalls, and breadth of the dry areas, and increased frequency of drought, and sea level rise, threatening to do so coastal areas, which includes more than a third of the population and more than half of the activity National Economic and also the breadth and the exacerbation of desertification, and then shrinking reserves of water (currently up to less than 1000 cubic meters per year per capita) and finally deteriorating quality of these water resources (pollution and salinity). constitute all of these results a threat to agricultural production and also on livelihoods and the health population in a range of areas,

The reason for this dire consequences on the country and the entire region to a doubling of the current rate of carbon dioxide in the atmosphere by the year 2100, according to the third report of the climate experts.

What is the size of the responsibility of Morocco in the potential of this situation? We can say they are very weak in comparison with the responsibility of developed countries, and in spite of that Morocco is committed Series reduce the aggravation of greenhouse gas emissions (in particular energy policy and the actions taken to reduce pollution). Morocco will fulfill its obligations towards the international system, but nevertheless raises attention to being there among the countries most at risk and which will suffer most from the consequences of climate change, which has become more and more possible!

I had this from the minister of environment! I tried to translate!

-Walid

Appendix G: Notes and Sketches from Notebook.

On Site Notes:

- Problem: need to convert kilns to natural gas to reduce pollution but natural gas kilns are not working.
- The natural gas kilns are ruining the zillij tiles.
- Traditional kilns use scrap woods and olive pits but produce a large amount of pollution.
- Natural gas produces a lot less pollution but cost more.
- It is the environmental problem that is the focus of our project.
- Even though the gas costs more the government is willing to subsidize half of that cost.
- Both kilns use the same heat profile when firing the tiles.

- Tiles don’t have the same colors and finish as the ones produce in the traditional kilns.
- Using traditional lining in gas kilns helps produce a yield of 25% good tiles with the other 75% unusable.
- The tiles from the gas kilns shatter when they are struck with a hammer.
- The gas kilns are expensive but the Moroccan government will subsidize 80% of the cost.
- Ficola manufactures the natural gas kilns in Italy.
- Traditional glazes do not work when fired in the natural gas kilns.
- Traditional glaze use metals that oxidize in the kiln to make the colors: Brass=Green, Cobalt=Blue, Iron=Brown, Chromium=Red, Tin=White, and silicon oxide is used to make a shiny overcoat on the tiles.
- Tiles are fired for 5 hours with the doors to the kilns closed.
- 120 kilns out of 240 are operating at a time, each one consuming 80 bags of scrap wood at a cost of around 45 USD.
- The other 120 kilns are cooling, being unloaded, and then being cleaned.

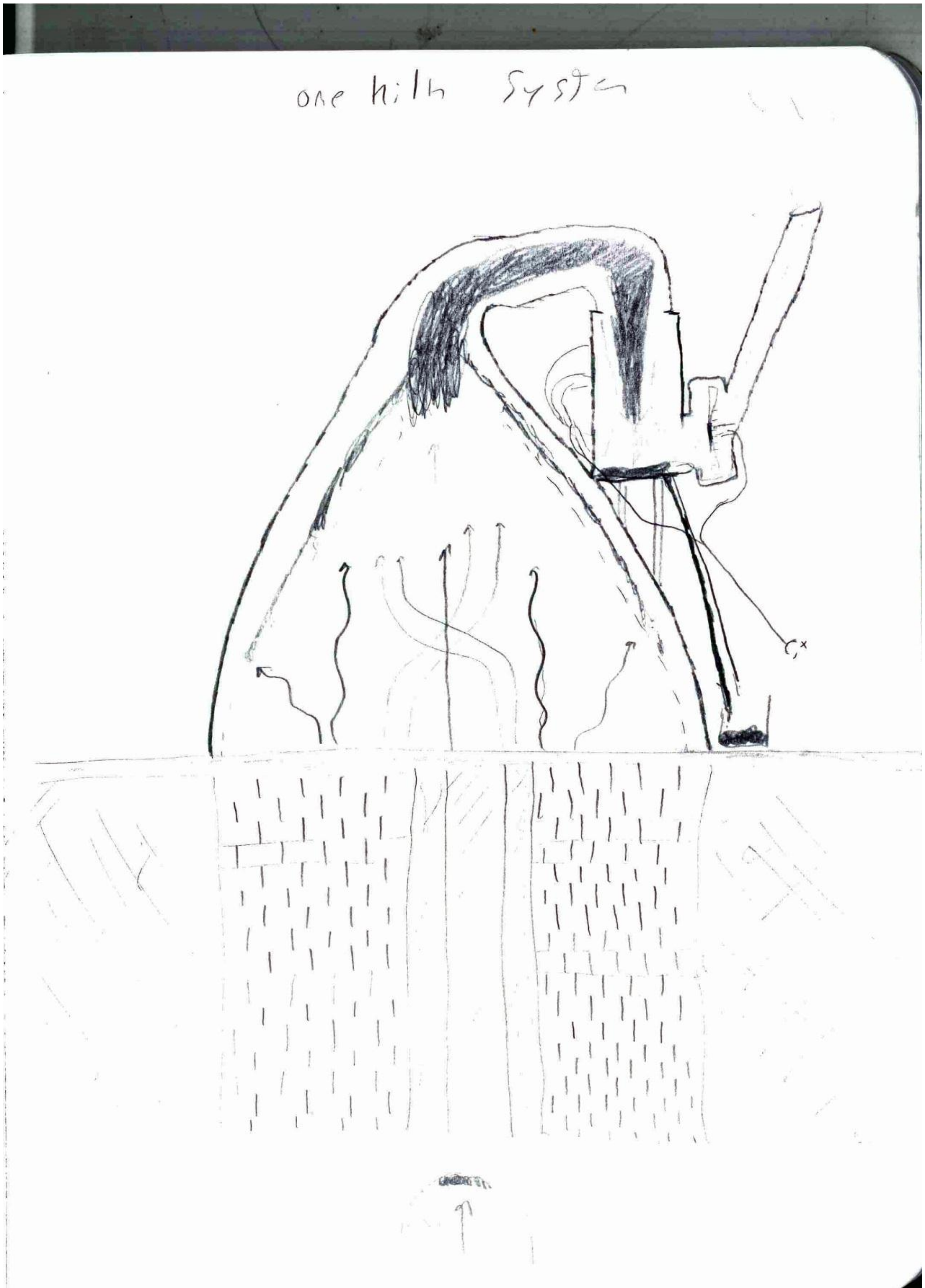


Figure 25: First sketch of a scrubber on a kiln.

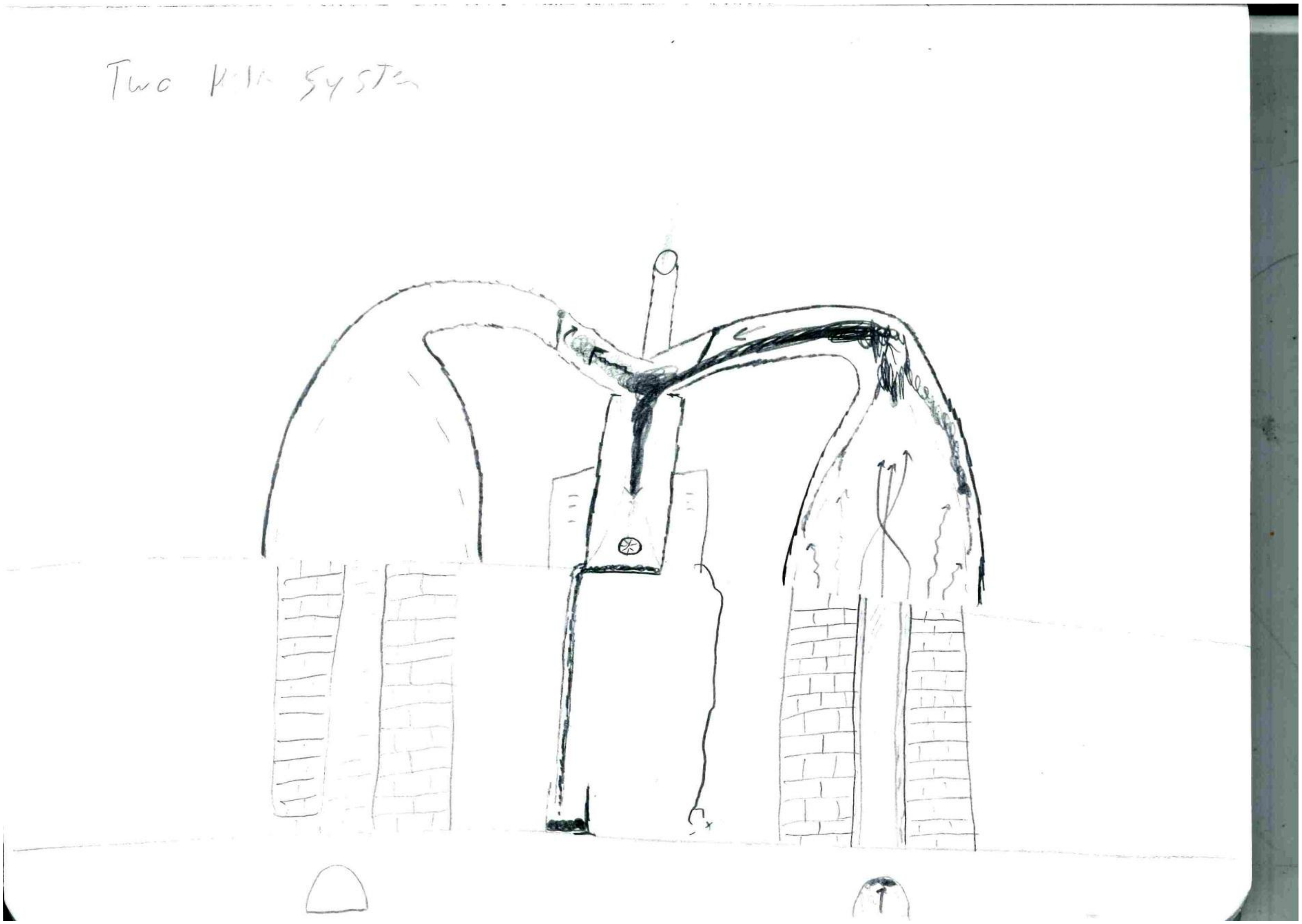
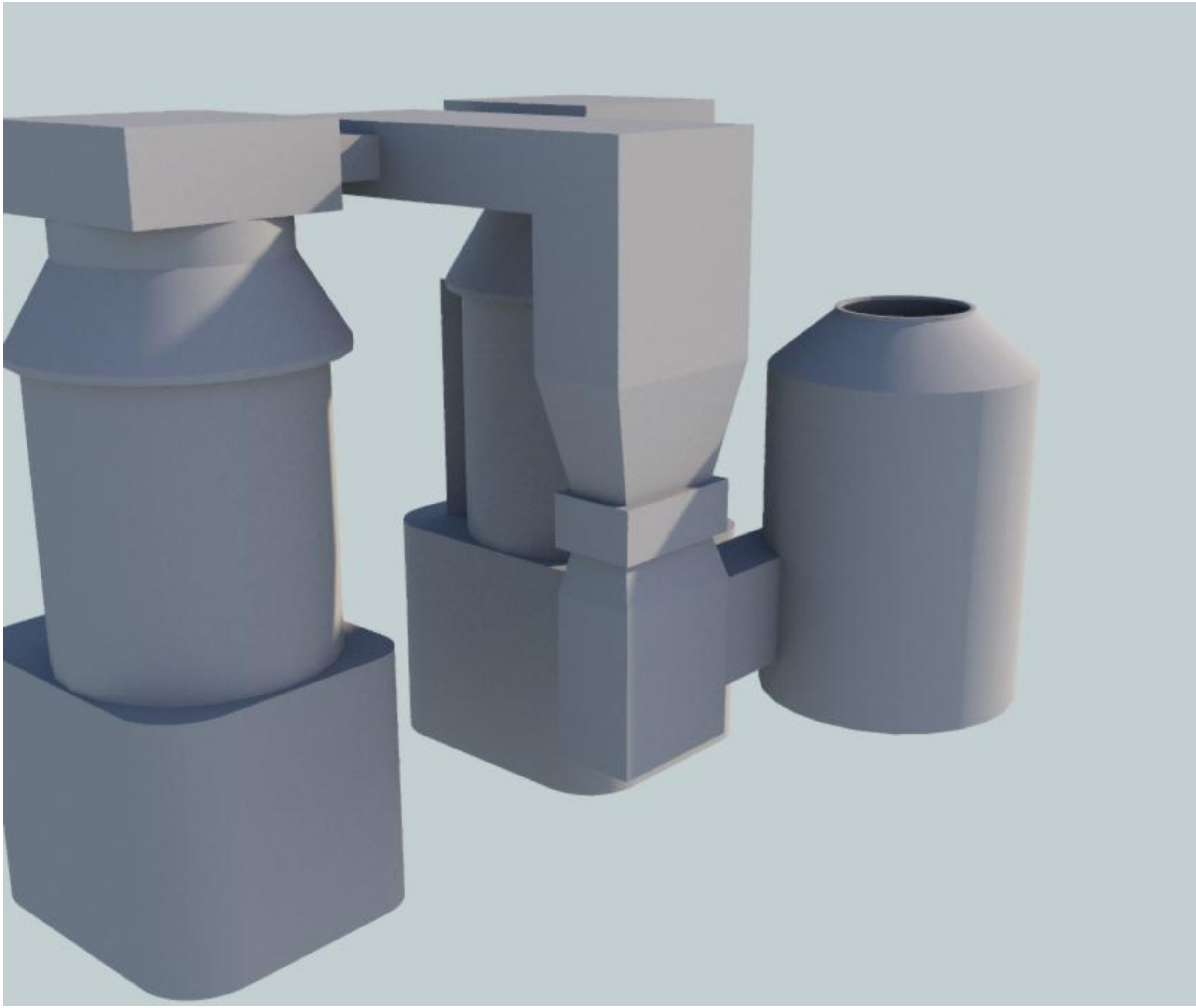
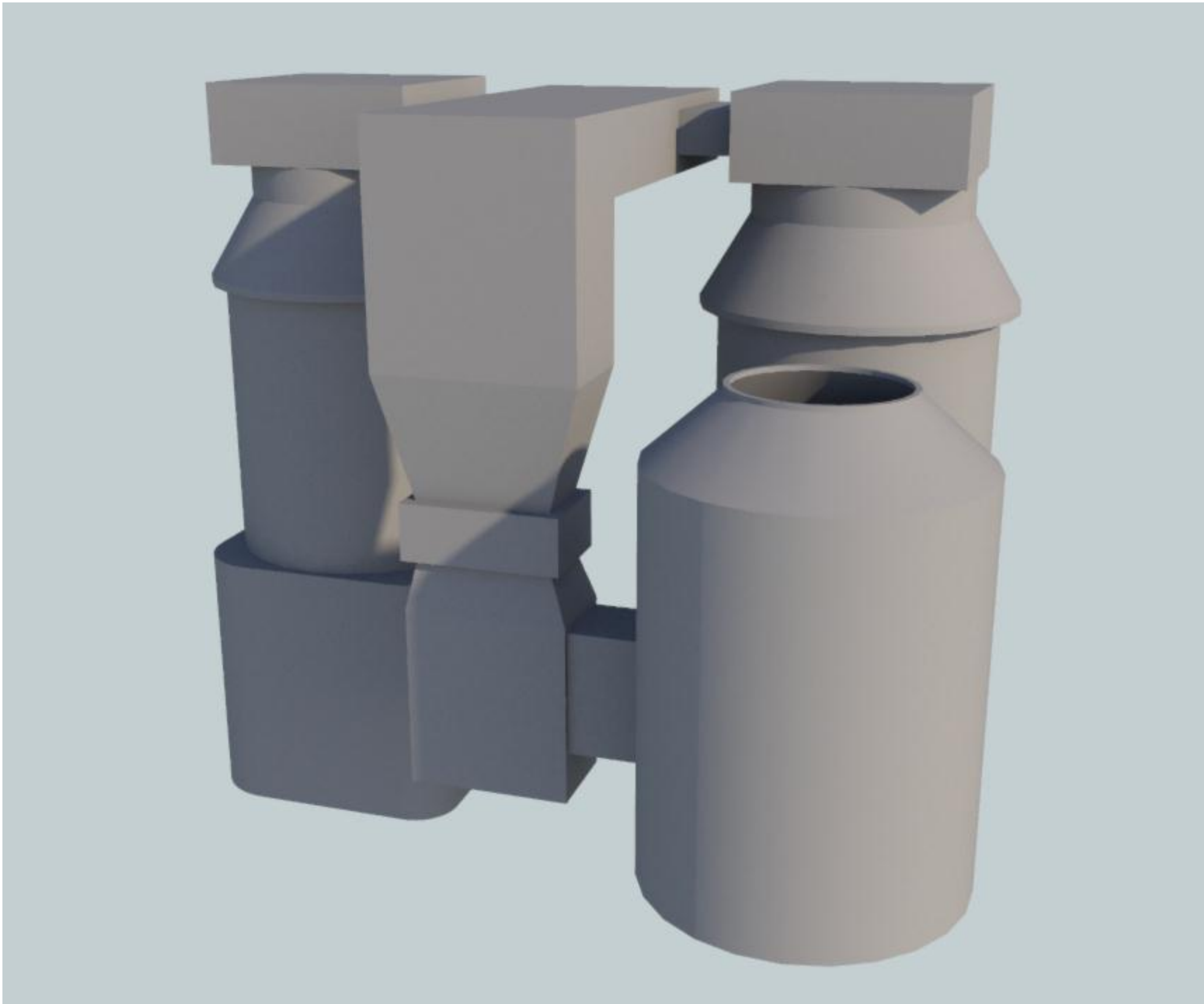
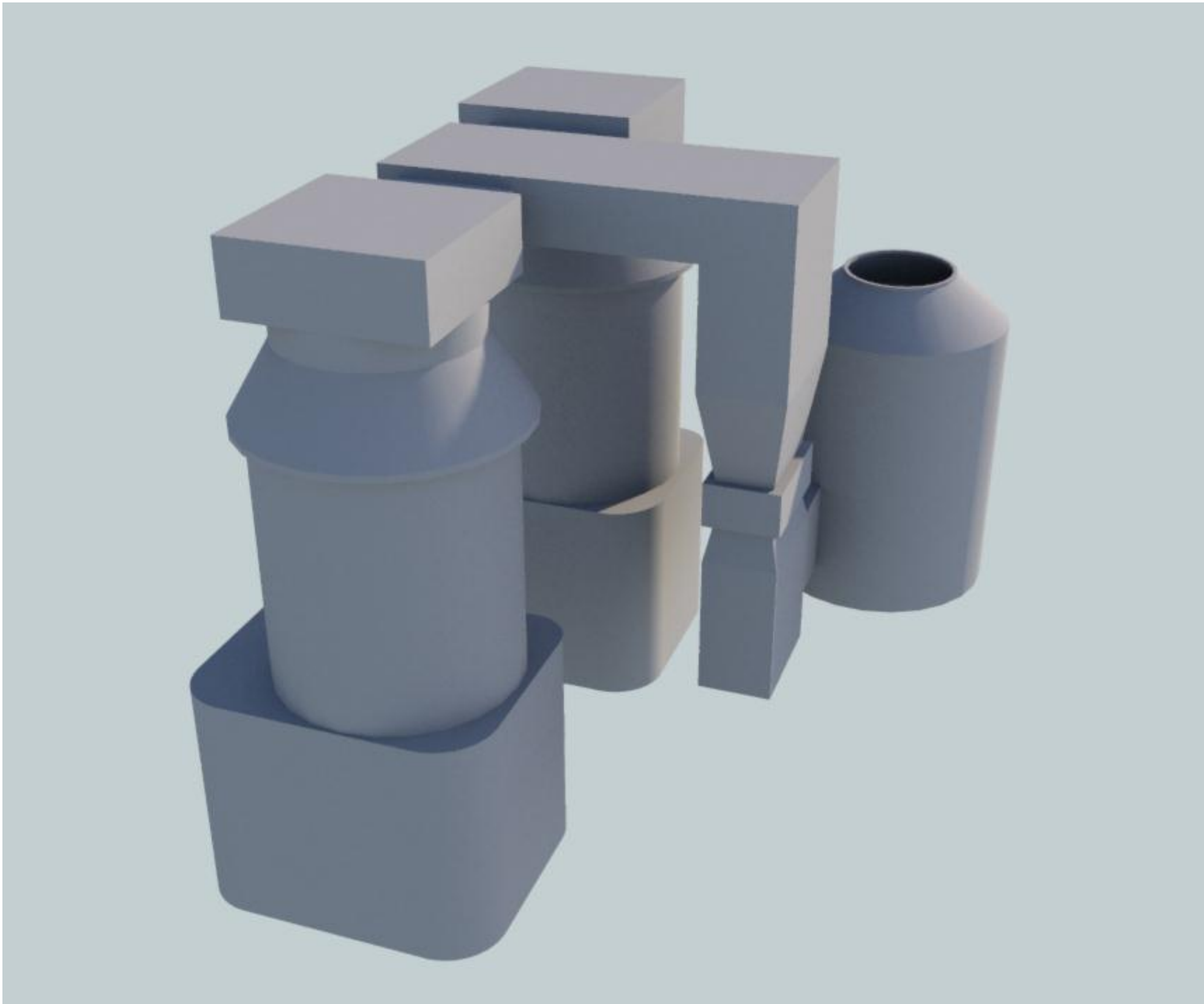


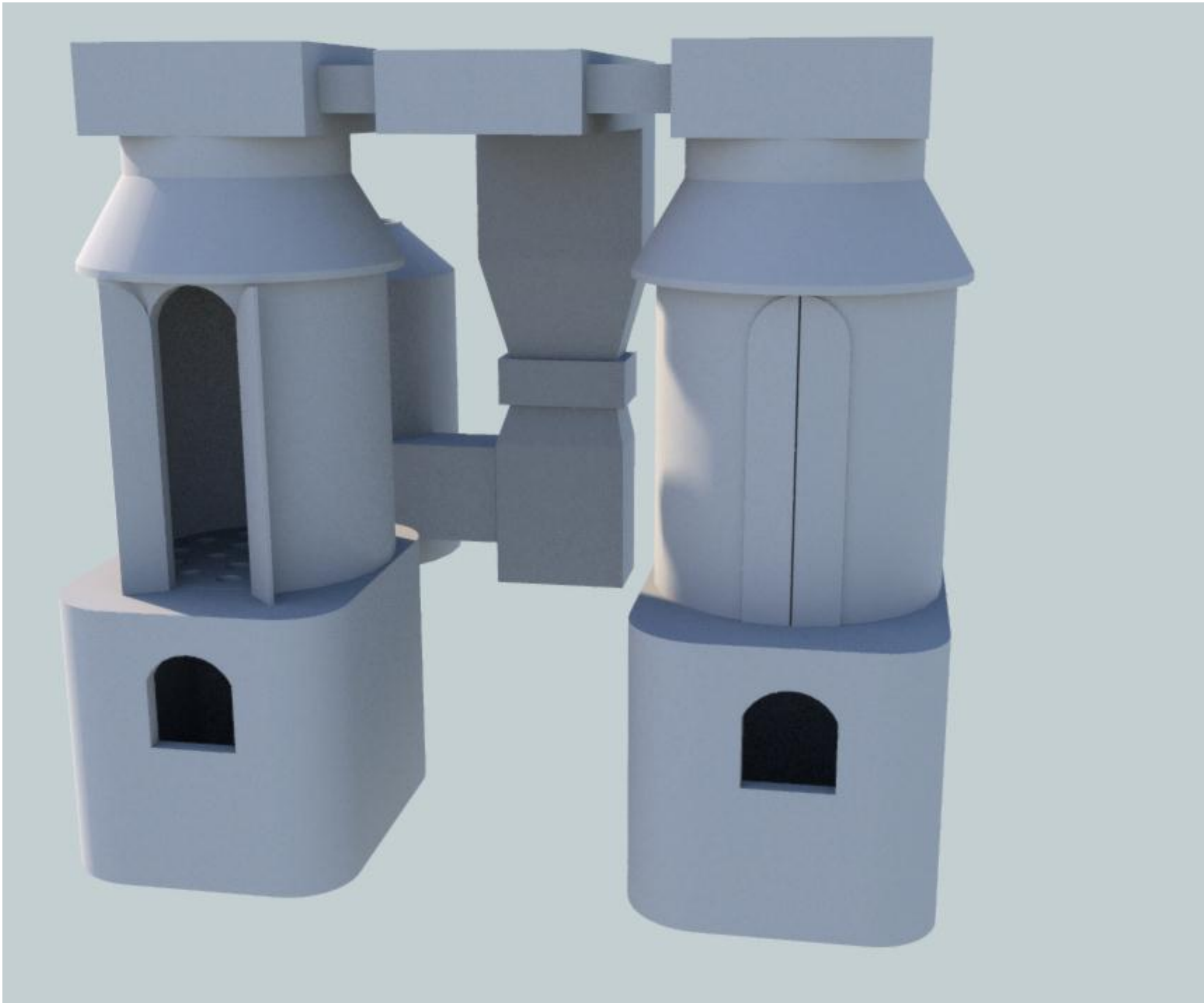
Figure 26: First sketch of a 2 kiln system

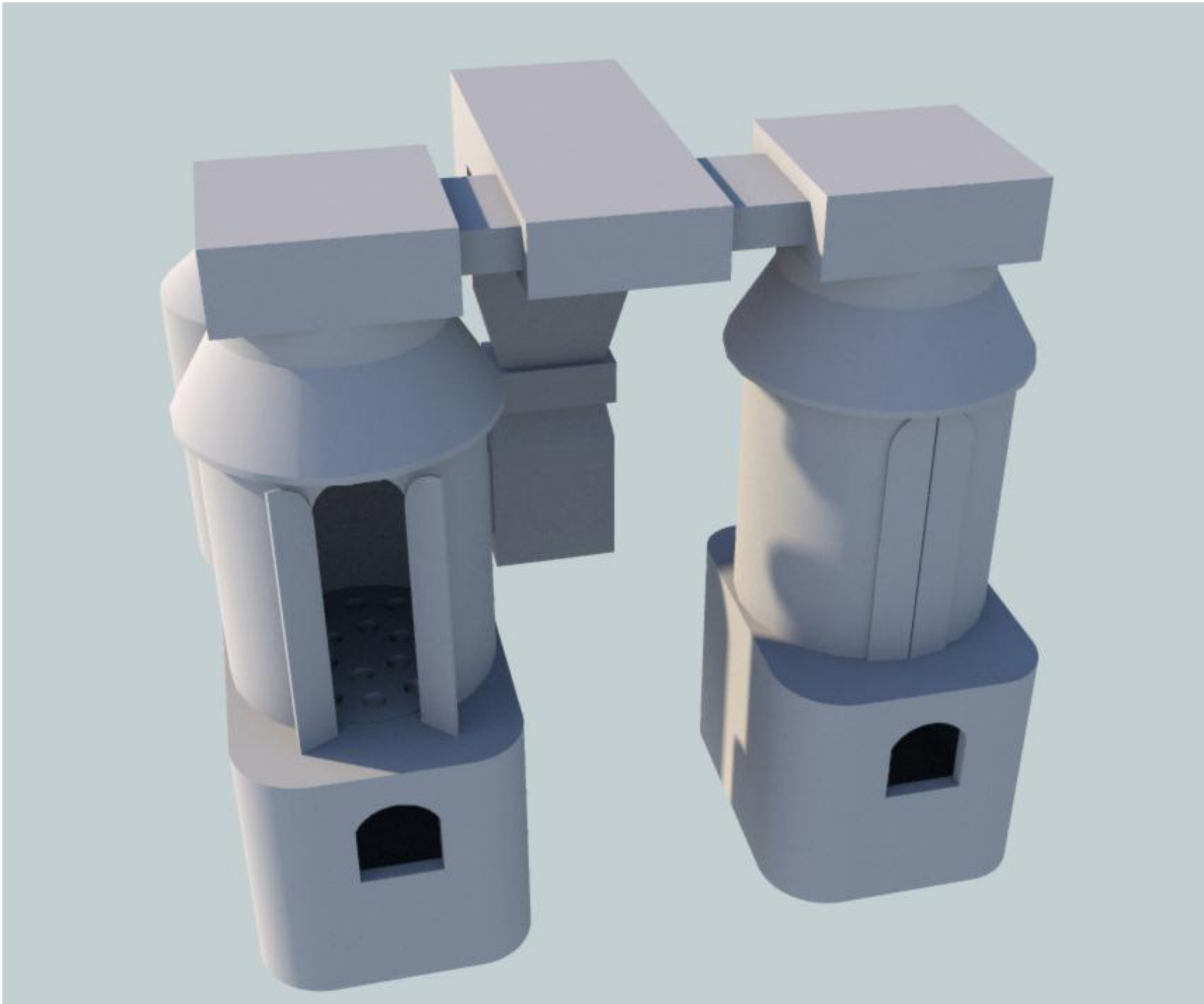
Appendix H: Computer Renderings of Venturi Scrubber Installed on Kilns

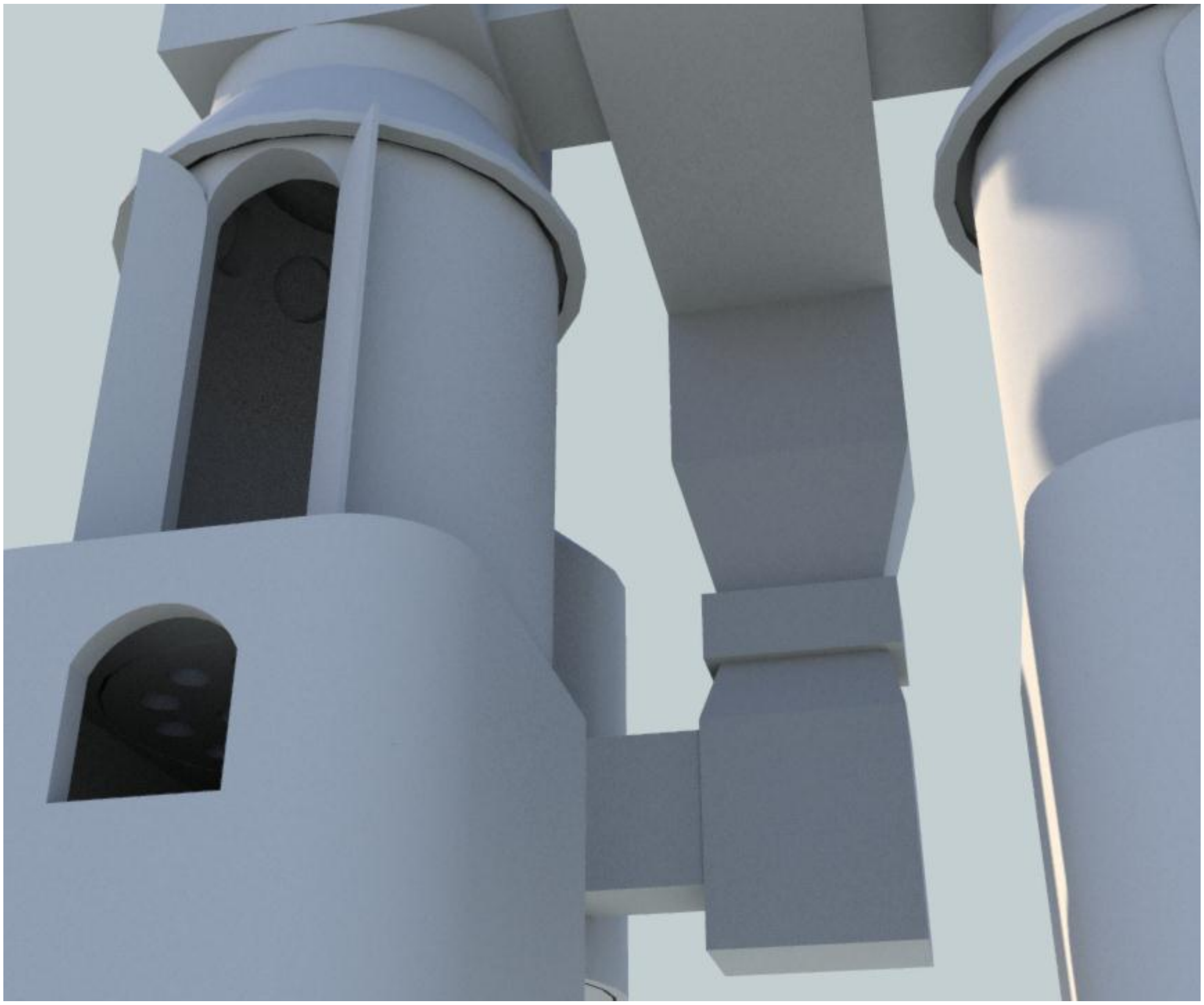


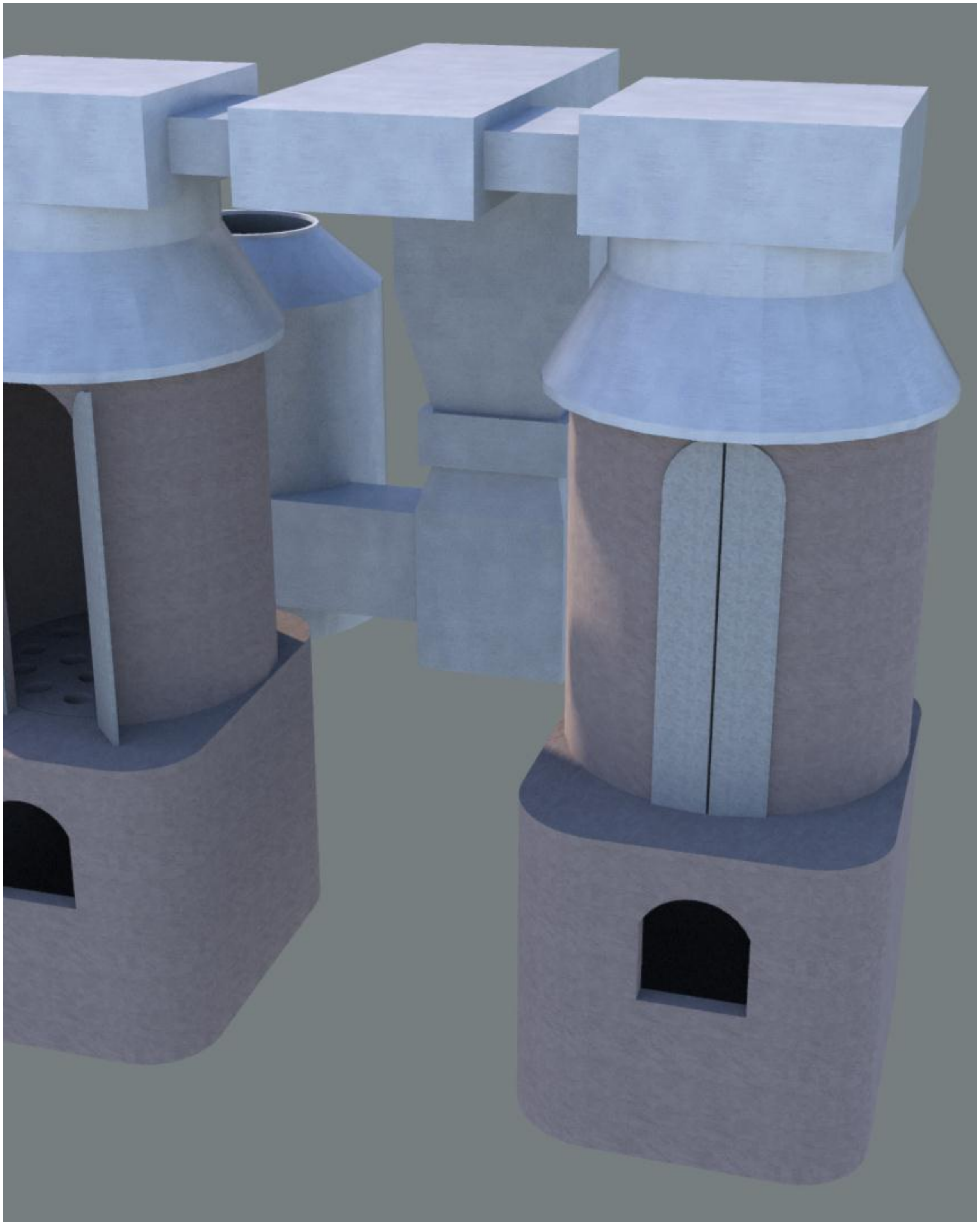


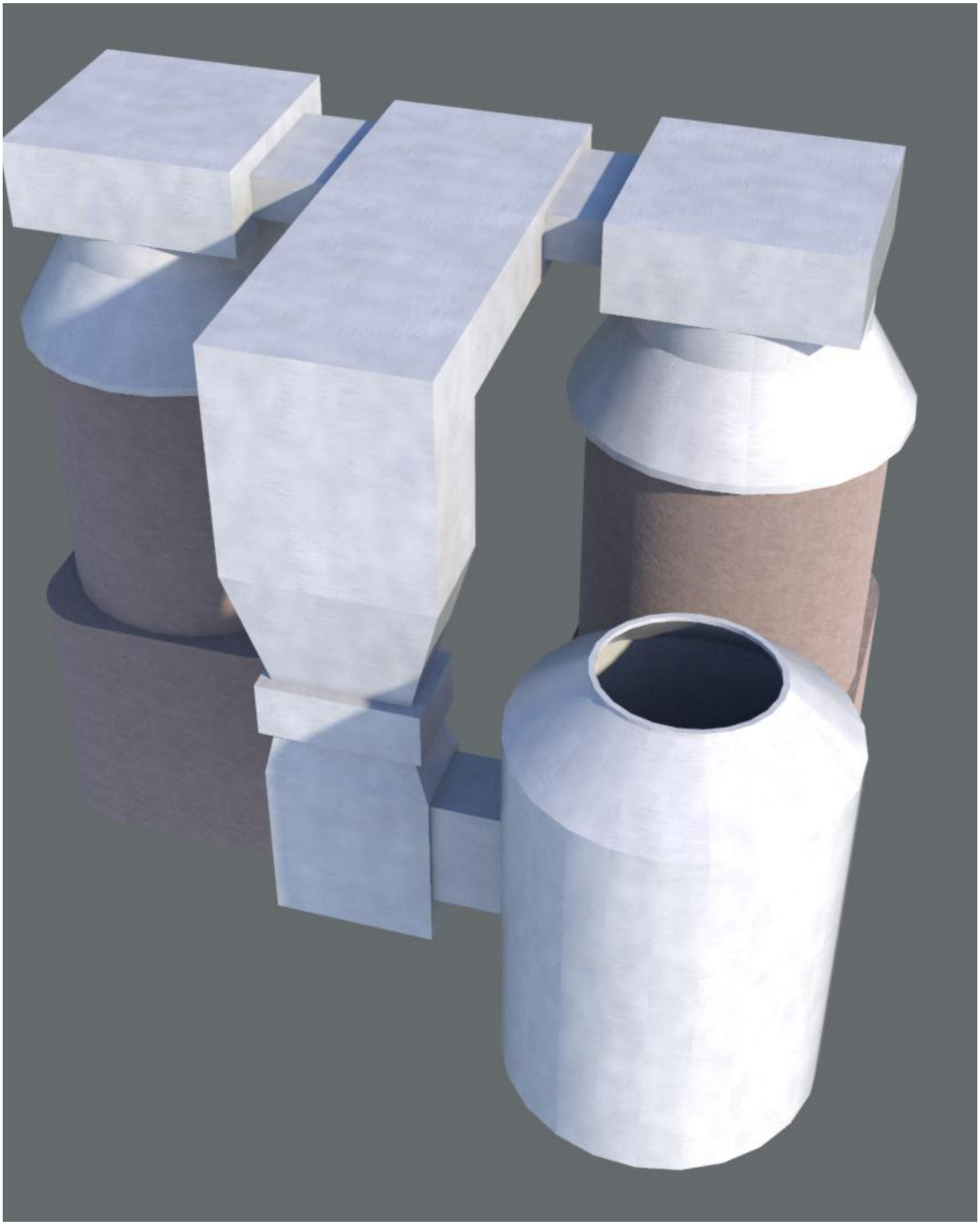


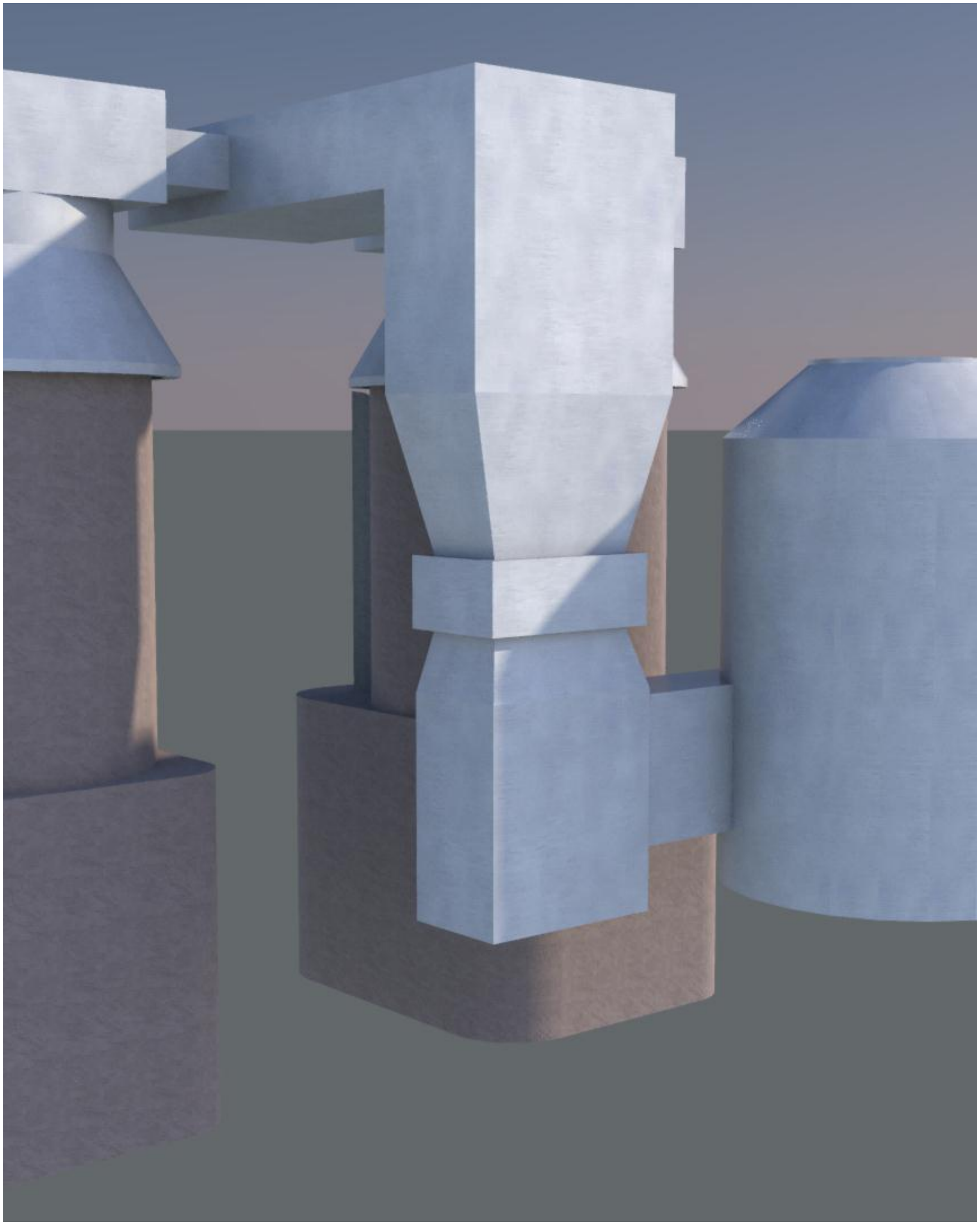


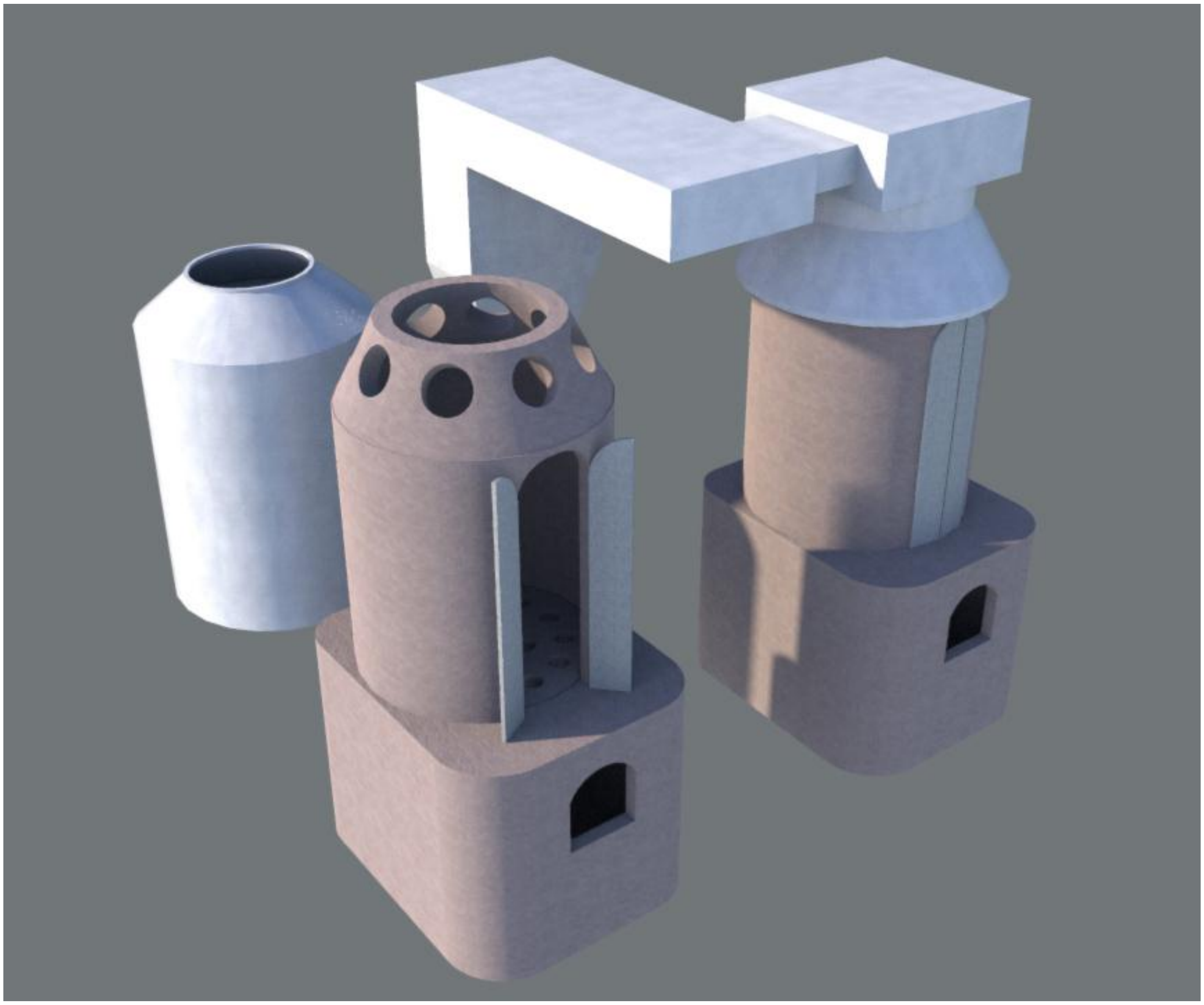












Appendix I: Additional Emissions Information

Wood fuel emissions vary depending on the composition of the wood which varies between different species of tree. Most wood contains around 70% cellulose material, 25% aromatics that bind the cellulose together, 5% extractives like terpines, resin acids, fatty acids, and phenols. Wood also contains somewhere between 0.2-3%. It should also be noted that fuel wood from construction and demolition waste, i.e. scrap wood, can be expected to contain more bits of dirt, drywall, plastic, and metal which along with paint cause many additional toxic emissions especially heavy metal emissions. Of the ninety organic compounds and twenty six trace elements identified in wood combustions emissions, the United States Environmental Protection Agency identified the compounds in the list below as candidates for concern (Beauchemin and Tampier, 2008).

Candidate Pollutants of Concern include:

Acetaldehyde
Alpha-pinene
Beta-pinene
Carbon monoxide (CO)
Formaldehyde
Methanol
Naphthalene
Toluene
Total phenols
Turpentine
PAHs
2,3,7,8 Tetrachlorodibenzo-p-dioxin (TCDD)
2,3,7,8-Tetrachlorodibenzo-p-furan
Hydrogen sulphide
Nitrogen oxides (NOx)
Beryllium
Cadmium and compounds
Chromium (II) compounds, as Cr
Chromium (III) compounds, Cr
Chromium (metal)

Chromium (total)
Chromium, hexavalent metal and compounds
Cobalt as Co metal Dust and fume
Cobalt carbonyl as Co
Copper, Dusts and mists, as Cu3
Copper, Fume
Iron
Lead arsenate, as Pb3 (A2O4)
Lead chromate, as Cr
Lead compounds
Magnesium
Manganese
Molybdenum
Nickel and compounds
Particulate matter (PM)
Phosphorus
Selenium
Silver
Thallium
Zinc
Arsenic and inorganic arsenic compounds
Mercury
Hydrochloric acid
Sulphuric acid
Sulphur dioxide (SO2)

All of these Particulates can be controlled using scrubbers and good combustions practices (I.E. steady, high heat to ensure complete combustion).

The characteristics of both the wood and the subsequent combustion heavily influence the quantity and composition of the emissions emitted. Particulate size is also directly related to combustion efficiency whereas combustions efficiency drops particulate size increases and vice versa. A dry wood that yields a hotter flame also yields almost twice as much oxides of nitrogen per a GJ. The presence of carbon monoxide is also a sign of incomplete combustion because carbon is oxidized in two stages, first it oxidizes into CO and then the CO is oxidized into CO_2, so in an incomplete combustion much more CO and less CO_2 is created. Finally an incomplete combustion can also lead to vast quantites of polyaromatic hy drocarbons and volatile organic componds. In an incomplete combustion the aromatics are only able to partialy oxidize into two or three ring aromatics like, anthracene, benzaldehyde, benzo (a) pyrene, chrysene, ethylbenzene, and fluoranthene (Beauchemin and Tampier, 2008)

Bibliography

Agrawal, U. (2008). *Globalisation poverty and culture*. Delhi, IND: Global Media.

Air Pollution Control Technology Fact Sheet – Fabric Filter. Retrieved from http://www.epa.gov/ttnchie1/mkb/documents/ff-pulse.pdf

Air Pollution Control Technology Fact Sheet – Venturi Scrubber. Retrieved from http://www.epa.gov/ttnchie1/mkb/documents/fventuri.pdf

Alavi, J., Sallem, K., Small, M. H., &Yasin, M. (2011). An assessment of the competitiveness of the Moroccan tourism industry; benchmarking implications. *Benchmarking, 18*(1), 8 April 2012-6-22.

Art, genres, and periods. (2008). *New Encyclopedia of Africa,* 8 April 2012.

Background note: Morocco. Retrieved 4/8, 2012, from http://www.state.gov/r/pa/ei/bgn/5431.htm

Baghouse / Fabric Filter. Retrieved from http://www.neundorfer.com/knowledge_base/baghouse_fabric_filters.aspx

Balafrej, Taha. Morocco.

Barlow, M. (2001).The global monoculture. *Earth Island Journal, 32*(3), 32.

Beauchemin, Paul A., and Martin Tampier. "Emissions from Wood-Fired Combustion." *Emissions from Wood-Fired Combustion*. British Columbia Ministry of Environment, 30 June 2008. Web. 19 Sept. 2012. http://www.env.gov.bc.ca/epd/industrial/pulp_paper_lumber/pdf/emissions_report_08.pdf

Camfil Farr (2011). *High Efficiency Centrifugal Particulate Separators*. Retrieved from http://www.farrapc.com/products/cyclone/

Camfil Farr (2011). *How a Cyclone Dust Collector Works*. Retrieved from http://www.farrapc.com/products/cyclone/how-cyclone-works

CIA. (2012). *CIA world factbook: Morocco.* Retrieved April 1, 2012, from https://www.cia.gov/library/publications/the-world-factbook/geos/mo.html

Commission staff working paper (2004). . Brussels: Commission of the European Communities.

Control of Particulate Matter Emissions. Retrieved from http://www.epa.gov/apti/Materials/APTI%20413%20student/413%20Student%20Manual/SM_ch%205.pdf

"CONVERSION OF PERIODIC KILNS FROM COAL FIRING TO NATURAL GAS FOR FIRING GLAZED CLAY PRODUCTS*" (12/01/1933). *Journal of the American Ceramic Society (0002-7820)*, 16 (1-12), p. 141.

Coy, David W., Greiner, Gary P., Lawless, Phil A., McKenna, John D., Mycock, John C., Nunn, Arthur B., Turner, James H., Vatavuk, William M., Yamamoto, Toshiaki (September 1999). *Particulate Matter Controls*.

Dust Collector Cost (15 October 2003). Retrieved from http://www.matche.com/EquipCost/DustCollector.htm

Electrostatic Precipitator KnowledgeBase. Retrieved from http://www.neundorfer.com/knowledge_base/electrostatic_precipitators.aspx

EMIS (2012). "Venturi Scrubber." Retrieved from http://www.emis.vito.be/node/19424

Environmental & Ethical Tourism in Morocco. Retrieved from http://www.travel-exploration.com/page.cfm/Environment_Ethical_Tourism

EPA (29 January 2010). *Source Control Technology – Particulates*. Retrieved from http://www.epa.gov/apti/course422/ce6a.html

Faroqhi, S. (2009).*Artisans of empire: Crafts and craftspeople under the ottomans.* London, GBR: I.B.Tauris.

Faroqhi, S. B., &SadokDeguilhem, R. (2005).*Crafts and craftsmen of the Middle East: Fashioning the individual in the Muslim Mediterranean*. London, GBR: I.B. Tauris.

Further trade reforms would improve economic efficiency. (2003). (No. 215). Geneva: World Trade Organization. Retrieved from http://www.wto.org/english/tratop_e/tpr_e/tp215_e.htm

Gerard, Etienne, Scholarisation, apprenticeship and social differentiation. Analysis of the non-industrial craft sector in Morocco, International Journal of Educational Development, Volume 32, Issue 1, January 2012, Pages 172-178, ISSN 0738-0593, 10.1016/j.ijedudev.2011.05.005. (http://www.sciencedirect.com/science/article/pii/S0738059311000939)

Glasmeier, A. K. (2000). *Manufacturing time: Global competition in the watch industry, 1795-2000*. (1 ed., p. 309). New York: Guilford Press. Retrieved from http://books.google.com/books?id=cVUSauNST8EC&printsec=frontcover&source=gbs_ge_summary_r&cad=0

Housefield, James E. "Moroccan Ceramics And The Geography Of Invented Traditions*."*Geographical Review* 87.3 (1997): 401-07. Print.

How an Electrostatic Precipitator Works. Retrieved from http://web.njit.edu/~avs9/Procedure%20Draft%20Final.htm

Imhoff, D. (1998). Artisans in the global bazaar. *Whole Earth, 94*, 76.

JustMorocco. (2012). Retrieved 4/8, 2012, from http://www.justmorocco.com/default.cfm

Karrou, Mohammed. Climate Change and Drought Mitigation: Case of Morocco.

Les hommes bleu: Artisans of morocco. Retrieved 4/8, 2012, from http://www.leshommesbleu.com/

McPhee, C., & St-Onge, A. (2009).Case study: Al amana of morocco.*Journal of Enterprising Communities, 3*(1), 59.

Millennium Challenge Corporation. (2007). *Millennium Challenge Compact with the Kingdom of Morocco*.

Millennium Challenge Corporation. (2007). Millennium Challenge Compact with the Kingdom of Morocco.

US Embassy. (2007). United States Diplomatic Mission to Morocco. Retrieved from http://morocco.usembassy.gov/challenge.html

PA. *Natural Gas Combustion*. Tech. Environmental Protection Agency, n.d. Web. <http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf>.

Peace corps country overview for morocco. Retrieved April 1, 2012, from http://morocco.usembassy.gov/peacecorps.html

Rhodes, F. (2002).*Zillij: The art of Moroccan ceramics*. London: IC Publications, Inc.

Scrase, T. J. (2003). Precarious production: Globalization and artisan labour in the third world. *Third World Quarterly, 24*(3), 449-461.

“Solubility of Gases in Water." Engineering ToolBox. Retrieved from http://www.engineeringtoolbox.com/gases-solubility-water-d_1148.html

Staff, McGraw-Hill (01/01/2007). "Kiln" in *McGraw-Hill encyclopedia of science & technology (0-07-144143-3, 978-0-07-144143-8)*, (p. 578).

Stern, Brett (23 December 2003). *Pollution Control for Wood Burning Kilns*.

Strofylas, Aristides. "THE EXTRACTED OLIVE POMACE FOR FUEL." *ΠΥΡΗΝΟΞΥΛΟ*. ΣΤΡΟΦΥΛΑΣ ΑΡΙΣΤΕΙΔΗΣ , n.d. Web. 19 Sep 2012. <https://sites.google.com/site/pyrhnoxylo/pyrenelaiourgeia-1/to-pyrenoxylo-san-kausimo/anglika>.

Su, Felicia. "Smog as a Negative Externality." *All That Smog*. Unversity of California at Berkley, Spring 2002. Web. 26 Sept. 2012. <http://are.berkeley.edu/courses/EEP101/spring03/AllThatSmog/extern.html>.

The New York Times (10 November 2001). Delegates Approve Kyoto Rules. Retrieved from http://www.heatisonline.org/contentserver/objecthandlers/index.cfm?id=3822&method=full

University of Hawaii at Manoa (28 February 2010). Tropics: Global warming likely to significantly affect rainfall patterns.

Unknown. (1983). *The holy qur'an* (M. H. Shakir Trans.). Elmhurst, New York: TahrikeTarsile Qur'an, Inc.

US Embassy. (2007). *United States Diplomatic Mission to Morocco*. Retrieved from http://morocco.usembassy.gov/challenge.html

US Government. (2004). Millennium challenge corporation. Retrieved from http://www.mcc.gov/pages/about

US Government. (2004). *Millennium challenge corporation*. Retrieved from http://www.mcc.gov/pages/about

US Government. (2012). *Millennium challenge corporation*. Retrieved from http://www.mcc.gov/pages/countries/program/morocco-compact

US Government. (2012). Millennium challenge corporation. Retrieved from http://www.mcc.gov/pages/countries/program/morocco-compact

WadiBellamine, M. A. (2007).*The impact of globalization on small scale artisans in azrou, morocco.*(No. 1).

Wet Scrubbers. Retrieved from http://www.epa.state.oh.us/portals/27/engineer/eguides/scrubbers.pdf

“What is a catalytic converter and how does it work?" (01 April 2000). Retrieved from http://auto.howstuffworks.com/question66.htm