6,000 Years of Copper smelting:
Center for the Study of Copper Smelting in Ancient societies

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January 14, 2000

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Road leading into the site.
Abstract

In 1959 professor of archeology Beno Rothenberg began investigating the production of copper in the Sinai desert and Aravah region of southern Israel. He discovered over 650 previously unknown ancient copper mining and smelting sites. The Timna Valley is one of the most significant sites discovered and is believed to be the first site of copper production, beginning six-thousand years ago.

Within this rich historical context, I propose to build an international center for desert studies and copper production in ancient societies. Faculty, students, and researchers will examine desert climate, vegetation, and wildlife. Equally important, they will study the process of mining and smelting copper. The center will also be open to individual tourists and larger groups. Following an introductory lecture, tourists will produce their own small samples of copper.

The architecture of the building is driven from the nature of the smelting process. In this process, copper is chemically separated from impurities in a smelting furnace. Heavy metallic copper sinks to the bottom of the furnace. Slag forms above the copper and gas evaporates. The layers of the building mimic this process and are made from copper, slag, and glass.

The overall design theme of the building also seeks to demonstrate a clear interaction between building, landscape, and environment.

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Submitted to the department of Architecture in partial fulfillment of the requirements for the degree of MASTER OF ARCHITECTURE at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY
February, 2000

Thesis Supervisor: Bill Hubbard Jr.
Title: Adjunct Associate Professor of Architecture
The completion of this thesis involved many people and it would not have been possible without their constant guidance and support.

To my parents whose support and personal example transcends beyond words.

To my fiancée Rishona Teres ("Shoni") who assisted with the development of the project’s theme and from time to time would inject some helpful and critical thoughts.

I would also like to extend a thank you to architects Evyatar Erell and Isaac A. Meir ("Sakis") from the Center for Desert Architecture and Urban Planning of Midreshet Ben-Gurion in southern Israel who introduced me to the site and provided a good source for information.

In addition, many thanks to Mrs. Hilary Cohen from Kibbutz Elifaz near Timna Park who was a great contact person for literature and a video about Timna.

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My thesis readers Professors Eran Ben-Joseph and Heather Lechtman. Eran for sharing his Israeli perspective of desert design and landscaping. And Professor Lechtman for her helpful insights of copper mining and smelting.

Chris Luebkeman, our department’s structural engineer, who believes that my cable roof is buildable from a structural standpoint with some minor calculations and changes.

Finally, I am grateful for the constructive criticism of architects Moshe Safdie, Stanford Anderson, and Julie Messervy during my final thesis presentation.
# Table of Contents

<table>
<thead>
<tr>
<th>Acknowledgments</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>11</td>
</tr>
</tbody>
</table>

1. The Building Context
   - The Timna Valley                       | 14 |
   - Copper Production                       | 20 |
   - The Site: Be'er Ora                     | 24 |

2. Design in Development
   - Design Strategies                       | 8 |
   - Movement Toward the Building            | 40 |
   - Movement Through the Building           | 41 |

3. Final Design
   - Site Plan                                | 48 |
   - Floor Plan                               | 50 |
   - Sections                                 | 52 |
   - Perspectives                             | 54 |
   - Models                                   | 75 |
   - Components and Systems                   | 80 |

Summary                                               | 93 |
Bibliography                                          | 95 |
List of Images                                        | 97 |
Approximately six-thousand years ago, prehistoric man discovered copper and utilized it for the production of tools and works of art. Ever since this discovery, copper mining has been an important industry. The first copper mining and smelting sites were discovered at Timna in southern Israel. In the fourteenth through the twelfth centuries, BCE Egyptian expeditions established an enormous copper mining operation at Timna. The Romans in the second century and the Arabian conquests of the Mameluke Period continued mining operations at the Timna Valley.

Yet Timna is one of many historical copper smelting sites in this region. Other major copper production locations were discovered in the Fenan area in Jordan and in the Sinai Peninsula in Egypt. The copper production of these areas also spans the time from the Chalcolithic (4500-3100 BCE) to the Islamic Middle Age.

Within this rich historical context, I propose to build an international center for desert studies and copper production. The center will be built at Be’er Ora (in Hebrew, Well of Light), a short six miles south of Timna. Students, faculty, and researchers will engage in the study of desert climate, vegetation, and wildlife. They will also examine the process of mining and smelting copper ores and produce small copper samples. The proximity between Timna and Be’er Ora allows for a constant interaction between theoretical study in the classroom and physical exploration in the landscape.

The theme of the building is driven from the nature of the smelting process. In this process, copper is extracted from silica and other metals in a chemical reaction conducted in a smelting furnace. Following the chemical reaction, pure copper sinks to the bottom of the furnace. Slag forms above the copper and oxygen gas evaporates.

The architecture of the center mimics this process. The materials of the building’s lower levels grant a sense of darkness, weight, and density. The materials of the middle level reflect the light, air, and open quality of slag. The glass roof panels echo the transparency and fluidity of the evaporating oxygen gas.
1. The Building Context

The Timna Valley .................................................................14
Copper Production .............................................................20
The Site: Be' er Ora .............................................................25
The Timna Valley

Historical Background

Timna Valley is located approximately 48 miles (30 km) north of Eilat on the western side of the southern Aravah. The valley spreads over an area of 60 square miles (155 square kilometers). The shifting of the earth’s layers combined with dramatic changes in weather conditions over a period of millions of years created its horseshoe shape. Although Timna’s landscape is rich with unique rock formations of varying shapes, types, and colors, it is best known for its ancient copper mining and smelting sites.

During the course of history, few explored Timna. In 1861, J. Petherick was the first to mention that copper smelting took place in the valley. Following Petherick, archeologists A. Musil, F. Frank, and N. Glueck partly surveyed the site in 1902, 1934, and 1935 respectively. It was not until 1959 that Professor Beno Rothenberg began a full-scale, internationally-recognized expedition which he described as, “the first firm archaeological foundation for the history

1.0. Aerial view of the central massif of Timna. The three vertical formations in the center foreground are know as “King Solomon’s Pillars.” The Hathor Temple is immediately beneath the central “Pillar.”
Rothenberg discovered over 650 ancient sites in the large arid expanse of the southern Aravah, the Sinai, and the mountains of Jordan. He traces the area’s copper mining to the Chalcolithic and Early Bronze Age periods in the third and fourth millennium B.C.E. During these periods, copper miners and merchants from Arabia used this area as a bridge between Asia and Africa. The copper mining and smelting sites of Timna together with sites across the Sinai and southern Arabia were important stations along the ancient trade routes serving “as functional meeting places between East and West.”

The production of copper did not end at the conclusion of the Early Bronze-Age. Many artifacts discovered at Timna confirm that the plant was used in the following centuries. For example, Egyptian civilization flourished throughout the Bronze Ages. During their excavation in March 1969, Rothenberg’s team discovered a statue and a mask depicting the face of Hathor, the Egyptian goddess of the earth’s natural treasures. Further digging at the foot of Solomon’s Pillars led to the discovery of an entire temple dedicated to Hathor.


2 Rothenberg, 14.
During these prehistoric times, the extraction of copper from the layers of the earth was shrouded in mystery and entailed religious rituals that accompanied the work. The Egyptians believed that their gods determined success and failures in the copper industry, and as an act of insurance, they constantly supplicated them with gifts. For example, a large stone on the steps above the sanctuary of Hathor bares an engraving of the Egyptian King Ramses III making an offering to Hathor.⁴

These discoveries and many others suggest that the Egyptian pharaohs from Pharaoh Seti I through Ramses V of the New Kingdom established extensive copper production mining enterprises at Timna.

In the twelfth century B.C.E., Egypt’s power began to decline. Their copper mining expeditions at Timna followed suit and soon local tribes resumed control over the valley. Almost 1,500 years later, by the second century C.E., the Romans occupied the southern Aravah. Roman engineers of the Third Legion Cyrenaica restarted the abandoned copper industry. They intensified production of copper in the

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3 Rothenberg, 125-60.
4 The Timna Valley: Video available from Park Timna, Israel.

1.2. Rock-engraving of Ramesses III making an offering to the goddess Hathor. The lower icon between the two people identifies the King as Ramesses III.
1.3. Temple of Hathor (bottom).
area expanding their mining and smelting camps to Be’er Ora and other sites in the Aravah. However, when the Roman Empire began to break up, smelting activities at Timna once again came to an end. Copper mining continued at Timna during the Mameluke Period of the thirteenth century CE but on a much smaller, local scale. It was for another two-thousand years that Timna was once again transformed into a center for intensive copper production by Israel’s Timna Copper Mines Ltd. 5

From Rothenberg’s extensive research, it seems the Sinai and Timna were the main copper sources for prehistoric Palestine. But based on discoveries made by a German mining team, archeologists Weisgerber and Hauptmann, argue that even greater amounts of copper ores were produced at the Fenan Area of Trans-Jordan. In fact, they claim, “for protohistoric Palestine the area of Fenan must be regarded as the main copper producer. Sinai and Timna at that time never could have been this important because of their limited ore base or their proximity to Egypt.”6 Like Timna, Weisgerber and

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1.4. A small sandstone head statue of Hathor in its original place of discovery.
1.5. Mask of Egyptian goddess Hathor (bottom).

5 Rothenberg, 8-23.
Hauptmann depict, "copper production of the Fenan area spans the time from the Chalcolithic to the Islamic Middle Age." Traces of nearly every period can be seen through fragments of crude pottery, flint ax heads, stone hammers, and substantial quantities of slag and raw copper.

Perhaps Fenan was, in fact, a larger, more significant copper production site than Timna and the Sinai, but all three sites share similar mining and smelting techniques common to the region.

Weisgerber's and Hauptmann's Summary of Copper Production Periods

<table>
<thead>
<tr>
<th>Period</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalcolithic</td>
<td>4,500-3,100 BCE</td>
</tr>
<tr>
<td>Early Bronze Age</td>
<td>3,100-2,100 BCE</td>
</tr>
<tr>
<td>Middle Bronze Age</td>
<td>2,100-1,900 BCE</td>
</tr>
<tr>
<td>Iron Age I</td>
<td>1,200-1,000 BCE</td>
</tr>
<tr>
<td>Iron Age IIC</td>
<td>800-200 BCE</td>
</tr>
<tr>
<td>Nabatean Period</td>
<td>First Century CE</td>
</tr>
<tr>
<td>Roman Period</td>
<td>200-400 CE</td>
</tr>
<tr>
<td>Mameluke Period</td>
<td>Thirteenth Century CE</td>
</tr>
</tbody>
</table>

7 Weisgerber and Hauptmann, 56.

1.5a. This snake is an example of ancient works of art made from copper. It is a Midianite copper serpent found in the central shrine of the Egyptian temple in its Midianite phase.
1.6, 1.7. Map of Israel and the Aravah region.
Six thousand years ago, prehistoric man discovered copper concentrates in layers of partially exposed sandstone. The stones contained 60% pure copper and produced metallic copper when smelted at high temperatures. However, the concentration of copper above ground became scarce so copper had to be removed from the surface of the rocks by open mining. Over the centuries, the miners improved and refined their working techniques. By the third millennium B.C.E., the tunneled mine had become more narrow and round.\(^8\)

A new era in copper mining began in the middle of the second millennium B.C.E. During this period, archeologists discovered two distinctly different types of mines. In the first and older type of mine, for example, miners used stone hammers to create large openings in the earth and mine the copper. However, the invention of new bronze and iron tools enabled the chiseling of larger openings and eventually to the formation of the second mine which is in the formation of a mine shaft. The vertical shaft descended to a depth of dozens of feet below ground. Niches on the walls of the shaft served as steeping stones for the miners giving them foot holes to lower themselves down into the mines. Connected to the vertical shafts were many offshoot horizontal galleries dug by ancient miners searching for concentrated layers of copper ore. The miners crawled through these galleries and chiseled the copper from the stone walls. They brought copper back up to the surface of the earth and transferred it to ground level smelting camps. They stored the copper ore in pits until it was ready to be smelted.

\(^8\) Timna video.
Smelting

Throughout the ages, copper smelters of the Aravah utilized almost identical smelting techniques in which they produced metallic copper from copper ores without a previous roasting process. They ground the copper ore into fine powder and placed it into the smelting furnace with bits of crushed wood and finely ground fluxes such as iron or manganese oxides, limestone or sea shells. The furnace was dug into the ground and had stone walls insulated with clay and mortar. Next to the furnace top was an additional niche that was used to remove the slag. The fire in the furnace was fanned with billows. The copper artisans raised the heat to temperatures between 1180-1350°C. Furnaces remained at these temperatures for several hours before they were filled with the powered mixture. During the smelting process, the ore separated into several elements. The heavy metallic copper globules tended to sink through the fluid slag—a byproduct of copper production—to the bottom of the furnace, while the light slag floated to the top. At the end of the process, which took about seven hours, copper artisans opened the furnace and drained the slag into the niche. The copper ingots remained inside the furnace and were the main product of the Timna plant. From here, they transported good qualities of metallic copper from Timna to the port at the Gulf of the Red Sea. They shipped the copper loaves to many other parts of the Middle East but mostly to Egypt where they used it to fashion tools and works of art.9

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9 Rothenberg, 235-40.
The Building Context

The Mining Process

1. Aerial photo of the hundreds of mine shafts that were either covered by the miners or by shifting sand and sediment over time.

2. First the miners dug vertical shafts. The shafts reached hundreds of feet below ground.

3. Once the vertical shafts were completed, the miners dug horizontal shafts leading to larger galleries inside the slopes. The lower photograph shows the chiseled marks on the walls by the Roman miners.

4. The miners transported copper ore to the surface using vertical pullies. They stored the ore in pits until smelting.
The Smelting Process

During the smelting process, the ore separated into several elements. The heavy metallic copper globules tended to sink through the fluid slag—a byproduct of copper production—to the bottom of the furnace, while the light slag floated to the top. At the end of the process, which took about seven hours, copper artisans opened the furnace and drained the slag into the niche.

Chemical Reactions of Reduction Smelting:

\[
\begin{align*}
\text{Fe}_2\text{O}_3 + \text{CO}_2 & \rightarrow 2\text{FeO} + \text{CO}_2 \\
2\text{FeO} + \text{SiO}_2 & \rightarrow 2\text{FeO} \text{ SiO}_2 \quad \text{(slag)} \\
2\text{CO} + \text{O}_2 & \rightarrow \text{CO}_2 \\
\text{CO} + \text{CuCO}_3 & \rightarrow 2\text{CO}_2 + \text{Cu} \quad \text{(metallic)}
\end{align*}
\]
**The Site: Be’er Ora**

Be’er Ora is my site for the following reasons. First, Timna Valley is mostly virgin green land or “sacred ground” that must remain untouched as much as possible for the preservation of its rare archeological discoveries and sensitive landscape. In contrast, Be’er Ora is brown land since the Israeli army already occupied it with its barracks and fire ranges. I would rather “recycle” the brown lands of Be’er Ora and attempt to repair some of the damage inflicted by the military than tamper with the green, sensitive land at Timna. Second, from the analysis above, we observed that Timna was not the only copper mining and smelting field in the region. The Sinai in Egypt and the Fenan Valley in Jordan are also rich with copper excavations. The study center that I am designing will be open to Israeli as well as international students from the Middle East and all over the world. The close proximity between Timna and Be’er Ora allows for a slight independence from Timna, while at the same time, students can travel back and forth between both sites in a matter of minutes. Finally the beauty of Be’er Ora, particularly its bowl-shape topography, was a big factor in choosing this site.

**Historical Background:**

Be’er Ora is a site located approximately six miles south of Timna and ten miles north of Eilat. An ancient well at the site currently provides water to a small nearby settlement. The well also provided water to the city of Eilat during its first period of development. A group of a few bedouin families from the tribe of Alkuat dwelled around the well and called it Bi’r Hindis which in Arabic means: the Well of the Moonless or Dark Night.10 Later, Jewish settlers converted the name into Be’er Ora—Well of Light. Due to the close relationship between the Arabic name Hindis and the Hebrew name Handasah (engineering), in the beginning the settlers first named the site Be’er Handasah or “the Well of Engineering” in honor of the Chel Handasah—the Corps of Engineers—that paved the road from northern Israel to Eilat.11

During his excavations in the area, Rothenberg uncovered the remains of three smelting furnaces and other evidence revealing considerable smelting activities at the site. He discovered large amounts of heavy, very dark slag in the shape of circles with holes in their cen-
Rothenberg believed that the copper “smelters of the Roman period regularly used slag as building material.” However “from the Byzantine period to the Early Arabic period and, in fact, up to medieval times,” states Rothenberg, “all copper-smelting activities in the area [of Be’er Ora] covered by the expedition were of minor local importance only and were never on a higher level than ‘home industries.’”

Contemporary History

Throughout the history of Jewish settlement in Israel, sporadic waves of volunteering to various security services such as the British military, the Haganah, and finally the Israeli Defense Forces (IDF) was common. Between 1950-53, government officials attempted to organize volunteers into a movement with the mission of assisting new immigrants and settling the “remote” Negev and Aravah deserts. Following the discovery of water at the well of Be’er Ora, a decision was made to establish a youth village there for the training of young volunteers from different kibbutzim, moshavim, and other youth groups. On December 22, 1950, the first group of volunteers arrived at Be’er Ora for training and, from then on, thousands of students
with their faculty came to the area on a mission of building and settling the dry dunes of southern Israel. The volunteers mostly worked on military bases as well as paving roads, expanding the airport in Eilat, developing new settlements in the Aravah, and experimenting with crops suitable for the dry desert climate. The Ministry of Education supported the volunteering initiatives and expanded the movement by establishing other youth training facilities along the Aravah. Due to a shortage of funding and a declining general interest, however, only one other pre-military youth training base (GADNA) was created at Ein Yahav. This GADNA base only functioned for a limited period.\textsuperscript{13}

The GADNA base at Be’er Ora remained operational until the early nineties when it too was shut down due to its inappropriate and outdated construction. The Israeli Army donated the land to the Jewish National Fund (JNF) which commissioned the Center for Desert Architecture and Urban Planning of Ben-Gurion University to design a new JNF-GADNA Youth Village at Be’er Ora. Thus far, also probably do to a lack of funding, the new base exists only on paper while Be’er Ora remains as quiet and abandoned as its natural surroundings.

\textsuperscript{13} Yitzak Neshri, “From the Happenings in the Desert: Attempts to Develop the Aravah in the Early Fifties.” Cited in Eidan 6 1900-1960, 194-200.
The Site: Be’er Ora

1.25. The GADNA Camp at Be’er Ora in its early days during the 1950s.
Climate

The Jewish National Fund commissioned architects from the Center for Desert Architecture and Urban Planning of Ben-Gurion University to design a new GADNA Youth village in Be'er Ora. Before they embarked in the design process, they conducted a survey of the site and concluded that:

"The climactic conditions in Be'er-Ora are amongst the hardest in Israel, particularly in the summer: daily maximum temperatures average close to 40°C, relative humidity drops to 20-25% in mid day. Solar intensity on a horizontal surface in Be'er-Ora in mid summer days is close to 1kw/m², which is one of the highest intensities in the world."\(^{14}\)

Average Temperature and Rain Fall for the Aravah Area:

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
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<th>Oct</th>
<th>Nov</th>
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</thead>
<tbody>
<tr>
<td>MAX (°C)</td>
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<td>23</td>
<td>26</td>
<td>31</td>
<td>36</td>
<td>38</td>
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<td>40</td>
<td>37</td>
<td>33</td>
<td>28</td>
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<td>31</td>
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<tr>
<td>MAX (F)</td>
<td>70</td>
<td>73</td>
<td>79</td>
<td>88</td>
<td>97</td>
<td>100</td>
<td>102</td>
<td>104</td>
<td>99</td>
<td>91</td>
<td>82</td>
<td>73</td>
<td>88</td>
</tr>
<tr>
<td>MIN (°C)</td>
<td>10</td>
<td>11</td>
<td>14</td>
<td>18</td>
<td>17</td>
<td>24</td>
<td>26</td>
<td>26</td>
<td>25</td>
<td>21</td>
<td>16</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>MIN (F)</td>
<td>50</td>
<td>52</td>
<td>57</td>
<td>64</td>
<td>63</td>
<td>75</td>
<td>79</td>
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<td>77</td>
<td>70</td>
<td>61</td>
<td>54</td>
<td>64</td>
</tr>
<tr>
<td>RAIN (mm)</td>
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<td>8</td>
<td>8</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>29</td>
</tr>
<tr>
<td>RAIN (inches)</td>
<td>0</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>1</td>
</tr>
</tbody>
</table>

\(^{14}\) http://www.bgu.ac.il/CDAUP/
1.26. Detailed map of Be'er-Ora location.
The Building Context

Movement from the main road to the site

1. At the Junction between Dead Sea/Eilat Road and 2 mile Road into Be'er-Ora. (Image numbers correspond to map)
2. Driving down the Road
3. Driving down the Road with the site in the distance.
4. At the main gate of the abandon GADNA Base of Be'er-Ora (top far right).

Map of the site area.
Aerial view of Be'er-Ora taken from north to south. Building Location in blocked area.
1.28. Aerial View of Be'er-Ora taken from south to north. Building Location.
Panorama of the site. Building Location.
The Site: Be'er-Ora
Study model.
2. Design in Development

Design Strategies ................................................................. 38
Movement Toward the Building ............................................... 40
Movement Through the Building ............................................ 42
Design Strategies

The underlining theme of the building is driven from the nature of the smelting process. In this process, copper is extracted from silica and other metals in a chemical reaction conducted in a smelting furnace. Following the chemical reaction, pure copper sinks to the bottom of the furnace. Slag forms above the copper and oxygen gas evaporates. Accordingly, the lower levels of the building are built from copper, the middle zone from slag, and the roof from glass panels.

In addition to the smelting process other elements contributed to the development of the building. First, the building was designed to accommodate the needs of specific clients. These clients are mostly individual tourists or larger groups of international secondary school and college students. A smaller group will also consists of senior researchers and archeologists who will conduct research at the site for longer periods of time.

In light of the fact that the number of expected visitors per-day during summer months will exceed the maximum capacity of the building, visitors will divide into two main groups. While one group remains at Be'er-Ora, the other will spend half a day at Timna. The groups will exchange locations at a certain time thereby insuring an equal experience at both sites.
Program

Number of people expected during any given summer day:

- 4 tour buses: 200 people
- 25 private cars: 100 people
- Researchers: 5-10 people
- Staff: 20 people
- Total people per day: 330 people

Break down of 300 people group into two.
Half stay at visiting center while other half off to the park.
300/2 = 150 people.

Each group will be made of 12 students so:
150/12 = 13 groups
Each group requires a seminar room for study during the day.
13 seminar rooms. Each will be about 20'x20' = 400sf.
400sf x 13 = 5,200sf

1 larger classroom for about four groups. 12 x 4 = 48 students. About 30' x 50' = 1,500sf

Other spaces include:

- Downstairs Large lecture hall for all 300 people
- Library and archival space: 4,000sf
- Office for staff: + library: 1,000sf
- Office for director and secretary: 600sf
- Researchers's facilities: 1,000sf
- Café: 3,000sf
- Exhibition Spaces: 3,000sf
- Restrooms (2 of each male and female): 1,000sf
- Mechanical: 1,000sf
- Storage: 2,000sf
The second main factor that influenced the design was the function of the building. The building is an education center with a focus on ancient copper mining. Therefore, visitors should recognize that they are in an abstraction of an ancient copper mine.

**Movement Toward the Building**

Once visitors leave their cars and buses in the parking lot near the main gate, they begin a journey by foot in the landscape. They walk along a path that cuts into the earth. As the earth rises due to the natural slope of the site, the path continues to move straight on the same level as its origin at the bottom of the site. Visitors walking along the path will have a sense of going down into the earth, much the same way ancient copper miners experienced as they moved through copper mines.

After about a five minute journey along the path, visitors suddenly encounter a garden or hidden oasis in front of the building. The oasis consists of a series of arched terraces with palm trees planted along the edges. A small stream of water flows from one terrace to the next.
The oasis contains spaces to sit and gather and also outdoor class-
rooms where students will produce small samples of pure copper.

The building's design demonstrates a high level of sensitivity to the
surrounding landscape. The contour lines of the hillside are a funda-
mental element in determining the form and shape of the building.
The walls of the building cut into the natural niche-like formation of
the contour lines creating three main zones: two on each size and a
large zone in between. The facade of the building is a bowel-like
shape echoing the shape of the smelting furnace. The round lower
auditorium excavated deep into the earth also brings to mind the
rounded copper mining tunnels.

**Movement Through the Building**

At the end of the path, visitors move through a doorway onto a
curved ramp. The ramp is a transition zone between the exterior path
and the interior cave-like exhibition space. The level of light in this
zone is controlled to allow a gradual adjustment between the exterior
bright sunlight and the much darker interior. At the bottom of the ramp visitors encounter the exhibition space which displays many artifacts such as sculptures, pottery, and copper and slag samples found at Timna and elsewhere.

After wandering through the exhibition space enjoying the exhibitions, visitors enter a large lecture hall. Here they view an introductory film and partake in a lecture explaining the process of ancient copper mining and smelting. The film and lecture also orient the groups to their location and the activities they are about to perform in the upper floors.

At the conclusion of the orientation, visitors proceed up a glass elevator—echoing the large elevators used in modern mining tunnels—to the middle zone. Visitors in this zone move up or down the ramps to their destinations. The ramps zig-zag back and forth in the same manner that one would move up and down a hill, not in one straight line but from side to side to negotiate the steep incline. The ramps also meet the American codes for handicap wheelchair accessibility. The slopes are built with a ratio of 1:12 meaning that every horizon-
tal 12ft they rise one foot. Also, there is a 5ft landing every 30ft which serves as a “doorway” into the horizontal gathering spaces along the ramps.

This sketch displays the movement of visitors up and down the second floor, or the slag level. The arrival point into this floor is on the middle right side.
Top: first study model showing the intention of creating a point of arrival from the ground floor to the middle level. From this point, visitors walk up or down ramps.

Bottom: Further development of the initial intention. Glass elevator begins to appear.

Top: view of same model from above.

Bottom: Movement of light down the glass elevator shaft to the gallery space. Visitors in the darker exhibition space will be drawn to the light.
Third model showing the relationship between the gallery space, auditorium, and the development of the upper level. White cubes are classrooms 20' x 20' each.

Study model of upper level. Initial design of ramps and gathering spaces along them.

Study models showing the development of the building. Images correspond to the design sequence beginning with the top left model on the opposite page.

Models are at a scale of 1" = 16'-0".
Sketch of pathway leading to the building.
3. Final Design

- Site Plan ................................................................. 48
- Floor Plans ............................................................. 50
- Sections ................................................................. 52
- Perspectives .......................................................... 54
- Final Model ............................................................ 75
- Components and Systems ........................................ 80
right: aerial view of site.
Left: view from parking lot, down the path, toward the building location.
Site plan. Blue lines are desert creeks. The creeks are dry and fill with water only when it rains once or twice a year.
Ground Floor Plan

1. Oasis
2. Exhibition space
3. Auditorium
4. Restrooms/storage
5. Glass elevator
6. Earth
Second Floor plan
1. Oasis
2. Cafe
3. Classroom zone
4. large open space
5. Bookstore / gift shop
6. Library
7. Offices
52 Final Design

Section A-A

1. Classroom Zone
2. Open Space
3. Lecture Hall
Section B-B

1. Oasis
2. Cafe
3. Lecture Hall
4. Elevator Shaft / Observatory Tower
5. Library
6. Archival Room
7. Mechanical Space
1. Movement through the path toward the building.

Numbers 1 and 2 in the plan above correspond to perspectives 1 and 2.
2. Turning a corner approaching the main entry.
1. At the entry to the Oasis and Building.
2. A peak around the corner into the Oasis.
1. Walking down the ramp toward the gallery space. On the left are the vents through which cooler air enters the building and is pulled by a fanning system to the second floor.
2. Movement into the gallery space in the copper level.
1. A view toward the elevator and auditorium.
2. Auditorium excavated into the earth.
1. In the elevator looking back toward the auditorium and gallery space.
2. Second floor in the large open space. A view through the glass-paneled roof toward the landscape. On the left is the bookstore.
1. Movement up to the library space. Bookshelves are inserted into the concrete walls.
2. This is the highest level of the building in the library. The glass elevator/observatory tower is to the right.
1. Gathering space for students in the classroom zone. Emergency door is on the right in the distance. During daytime, this door and others around the building are open to allow students easy access to the outdoors. Smoking is prohibited in the building.
2. Movement from the bookstore level down the ramps.
1. Down the ramp.
2. A view at the lowest part of the building looking upward.
1. Leaving the building down the glass elevator shaft and out the door in the distance. View looking through the glass elevator shaft.
2. View up the exit stairs.
1. View at the bottom of the oasis looking up the axis of palm trees.
2. At the western side of the oasis looking east.
Computer image of aerial View.
Final chipboard model.
Scale: 1" = 16' - 0"
1. Final Model, upper floor.
1. Final Model, lower floor.
Building Systems

The climactic conditions of Be’er-Ora are the most challenging in Israel. During the summer, daily maximum temperatures average close to 40°C, relative humidity drops to 20-25% in midday. To overcome these severe conditions and achieve thermal comfort with the lowest energy input, I integrated the following passive cooling systems with the building’s components.

Roof Design

Initial Design:
The roof is one of the most significant elements of the building that contributes to its climate control. Initially, I considered two fundamentally different roof systems. The first is an enclosed glass-roof similar to Jorg Schlaich’s cabled glass roof of the Flemish Council in Brussles. The second roof is a light tensile structure similar to the structures of the German structural engineer Frei Otto.

After much thought and deliberation, I chose the former for the following reasons. First, it provides better enclosure to the building. It protects the building from natural elements such as rain, wind, and sand and also from unwanted desert wildlife. Second, from an architectural perspective, the transparency of the glass allows for a visual connection to the sky. It's double-curved shape also better merges with the exterior surrounding hillside slopping in two directions and it creates a unique and special experience in the large interior open space. And finally, in response to the climate and environment, the glass roof better interacts with the passive cooling and heating systems. Some expressed concern that sunlight will penetrate though the glass; however, the glass roof is composed of special mirrored glass panels that deflect rather than absorb solar rays.

Final Roof Design
The final roof is composed from a matrix of double-layered laminated insulation mirrored glass panels. The panels are linked together at all three corners by a steel-framed triangular grid. Each panel in the grid is individually curved and rarely lies in the same plane as the next panel. The triangular grid allows for the formation of the roof's...
Final Design

The overall doubly-curved surface mirroring the curved slopes of the surrounding hillsides. The mirrored glass deflects hot sun rays and prevents the penetration of a large amount of solar heat into the building. At the same time, the transparency of the glass allows for a visual connection between the interior of the building and the exterior sky.

The triangular glass frames are suspended from a web of steel cables. The web is raised with large steel arms five feet above the encompassing concrete walls. Although it seldom rains at Be'er-Ora, the roof is completely water proof. Rain water slides down the 2ft gap between the cables and the glass and is collected in a drainage system at the bottom of the building. The roof also protects the building from strong winds and sandstorms common to the area.

The roof is an important component in the overall passive cooling system of the entire building. Just as the building is divided into three sectional layers—copper, slag, and glass—so too are there three climactic zones in the building: the extreme hot zone outside, the cooler and shaded larger interior open space, and finally, the air-conditioned class rooms on both sides of the large open space. The fol-

This model shows my initial proposal of designing the building with a tensile structured roof.
lowing passive cooling method is employed to cool the large open middle space.

**Passive Cooling and Ventilation System**

The air outside the building gathers in the sunken oasis area. Its interaction with the cooler sunken earth reduces its temperature by a few degrees. An evaporative cooling system installed on the facade further cools the air before it enters the lower copper vents. This evaporative cooling system is composed of small streams of water that flow from top to bottom of the facade. The water of the facade meets the water of the terraces in the oasis at the bottom of the slope.

**Daytime cooling**

Once inside the bottom floor, large fans installed on the back walls pull the cool air through the building ventilating its large open space. Simultaneously, warmer air in the main open space rises to the roof and meets the cooler air. A chimney effect occurs when the warm air hovering on the bottom surface of the glass roof meets the cool air. The cool air replaces the warm air and the building is constantly ventilated.

This is my final model. The roof of the building is made from a web of cables. The cables support a matrix of triangular mirrored glass panels.
Nighttime Cooling
The air temperatures of Be’er-Ora rapidly change between day and night due to the nature of the desert climate. To take advantage of these drastic temperature shifts the walls in the lower level of the building are partially made from phase changing materials. These materials absorb cool air during nighttime. When the sun rises in early morning the temperature begins to rise and, accordingly, the phase changing materials begin to release cool air into the upper building levels.
The Middle Open Space

The design intention of the middle zone is to grant a sense of the surrounding hillsides spilling into the building thus merging building with landscape. The combination of materials and arrangement of spaces fulfilled these intentions.

Materials
The middle open space which includes the encompassing walls, classrooms, steps, and ramps is made from concrete. The concrete has a natural earth-like quality which reinforces the notion of the hillside penetrating the building. The aggregate in the concrete mix is made from exposed crushed slag. The slag follows the general theme of the building driven from the smelting process.

Design
The middle open space follows the design language of well known landscape architect Lawrence Halprin. Halprin creates interesting large outdoor gathering spaces by shifting and changing heights and dimensions of platforms. The middle open space, therefore, is com-

posed of a series of gathering spaces along a ramp and stair system. The glass elevator transports visitors from the bottom floor to the center of the middle zone. Visitors walk up or down a series of ramps to their destinations. The ramps are fashioned after switchbacks used to get up steep hills. They are not in a straight line but are intersected by platforms and stairs creating an interesting journey along the way. Finally, the ramps meet the American codes for handicap wheelchair accessibility.

1. Point of arrival from lower level
2. Ramps
3. Gathering spaces along the ramps.
4. Cafe
Landscaping and Water

The Building

A garden or desert oasis faces the main facade of the building and functions as a transition space between the building itself and the natural landscape of Be’er-Ora. The oasis is composed of a series of arched terraces. Palm trees grow along the edges of the path and shelter the visitors from the hot sun. In addition, small streams of water—echoing the desert creeks of the site—flow along the edges of the terraces. The enclosed water system provides water for the vegetation of the oasis and also meets the water of the evaporative cooling system on the building’s facade.

3.6. Images showing Israeli landscape architect Shlomo Aronson’s notion of “Desert Creeks” flowing through the campus of Ben-Gurion University, Be’er Sheva and the plaza of Suzanne Delal Dance and Theater Center, Tel-Aviv (bottom).
"Desert creeks" flowing on the terraces and meeting the water of the evaporative cooling system at the bottom terrace.
The site:

Be‘er-Ora is encompassed by tall hills from three directions, north south, and west. It seldom rains at the site, but once or twice a year when it does rain, the hard, dry earth cannot absorb much water and it quickly flows down the contours. Large pools of water form in certain areas and trees and other desert vegetation will grow in areas where water gathers due to the nature of the contours.

Excluding the parking lot, the path, and the building, the rest of Be‘er-Ora will remain in its natural, undeveloped state. The existing abandon military structures will be cleared from the site. Visitors will wonder through the site enjoying its unique beauty. Trees in several locations will provide shade for the visitors.

3.8. Images showing erosion control through bays and ravines in the Negev Desert, Israel.
Site plan: The blue lines are desert creeks that form during rain fall. Trees and other vegetation grow in bays created by the creeks.
Pre-historic man began mining copper 6,000 years ago at the Timna Valley in southern Israel. Today, it is an amazing experience to visit Timna and explore ancient copper mines and smelting camps surrounded by beautiful landscapes and rock formations. Having viewed the ancient copper sites in the field, people will be interested in visiting an educational center with a focus on desert life and copper production.

Accordingly, the design of the center revolves around the process of copper production in which copper is separated from stone and other metals by a chemical reaction. The lower level of the center is made from copper and is excavated into the earth giving visitors a sense of a copper mine. The middle layer of the building is more open and spacious mimicking the qualities of slag. The roof of the center is made from glass representing the light, transparent, and almost “not there” qualities of the oxygen gas that evaporates from the smelting furnace.

In addition to the smelting process, the design of the building exhibits a sensitivity to its surrounding landscape of Be’er Ora. It is placed in a niche-like hillside and its walls flow with the contour lines. Rainwater will flow around the building in a series of canals and will gather in an aggregation system at the bottom. Other environment-friendly systems include an evaporative cooling system on the facade of the building and a passive ventilation system moving cooler air from the oasis, through the main open space, and out of vents above the library.


“The Timna Valley.” Video available from Park Timna, Israel.
Detail of Oasis.
All drawings, models, photographs, and computer renderings are by the author, Marc Steinberg, unless otherwise noted.

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<th>Image No.</th>
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<td>Rothenberg, 159.</td>
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<td>Rothenberg, 64.</td>
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<td>Kroker, p. 75.</td>
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<td>Rothenberg, 80.</td>
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<td>Kroker, p. 83.</td>
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<td>Kroker, p. 79.</td>
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<td>1.17</td>
<td>Kroker, p. 80.</td>
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<td>Rothenberg, 175.</td>
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<td>Rothenberg, 175.</td>
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<td>1.25</td>
<td>Neshri, p. 200.</td>
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<td>1.27, 1.28</td>
<td>Aerial Photo of Be’er Ora, Ofek Aerial Photos, Israel</td>
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<td>3.2</td>
<td>Axel Menge, <em>The Work of Jorg Schlaich and his Team,</em> 78.</td>
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<td>3.3</td>
<td>Roland, p. 126.</td>
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<tr>
<td>3.7</td>
<td>Aronson, 151.</td>
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