Solar Decathlon Africa

Artisanal Design Features for Team OCULUS
Net-Zero Solar House

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Rabat, Morocco Project Center
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Advisors
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Artisanal Design Features for Team OCULUS Net-Zero Solar House

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This report represents work of WPI undergraduate students submitted to the faculty as evidence of a degree requirement. WPI routinely publishes these reports on its website without editorial or peer review. For more information about the projects program at WPI, see http://www.wpi.edu/Academics/Projects
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Abstract

WPI will participate in the 2019 Solar Decathlon Africa with three partner universities to create an efficient, innovative, net-zero energy house. Our goal was to provide recommendations for the floor, insulation, and exterior envelope systems that are functional and aesthetic features of the Solar Decathlon entry. We interviewed, observed, and shadowed artisans to learn about technical details of three Moroccan crafts that will be incorporated into house features: zellige, leather, and wicker. After creating specification sheets and performing ranked analyses on the various options for each craft, we recommended using square zellige tiles, sheepskin leather poufs, and split laurel tree wicker for the flooring, insulation, and envelope systems.
Ann Le, Allison Sichler, Dakota Payette, and Jonathon Brownlow all contributed to the research, writing, and revision of this document. This table outlines each group member’s contributions to the project. Primary writers and editors are listed for report and creation of the deliverables.

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From left to right: Jonathon Brownlow, Allison Sichler, Ann Le, Dakota Payette
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The Solar Decathlon is a collegiate competition run by the U.S. Department of Energy which challenges students to create net-zero energy, innovative, and attractive houses. The main focus for this upcoming competition is to contribute to current knowledge of sustainable housing, specifically when it comes to housing in Africa. The African continent requires its own unique design considerations, and the hope is that participating teams will adapt to these needs while integrating regional sustainable raw materials and local cultural design aspects (Solar Decathlon Africa, 2018). The design phase for houses starts up to two years before the competition. During the actual competition, teams will have three weeks to construct their house. After the construction phase is complete, teams will compete in a series of contests designed to test many aspects of their house (SDA Rules, 2018).

WPI will be participating along with three partner universities from Morocco and Nigeria in the Solar Decathlon Africa, which will be held in September 2019 in Benguerir, Morocco. Together, the four universities will compete as Team OCULUS. Their design for the solar house plans to utilize a geodesic-like structure with a focus on local, sustainable, and affordable materials. The conceptual designs for the envelope of the OCULUS solar house and floor plans are shown in Figures 1 and 2. The house will be marketed for eco-tourism and used as a platform for education on zero energy buildings (El-Korchi & Van Dessel, 2018). The design features flexible space use which easily connects to the outdoor area (El-Korchi & Van Dessel, 2018). The team plans to use evaporative cooling to control the temperature, which in turn reduces energy draw to cool the house. They also plan to incorporate local Moroccan crafts in the interior and exterior design such as zellige for
the flooring system, leather poufs for insulation system, and wicker for the exterior
envelope system.

The goal for this project was to provide our recommendations for the flooring,
insulation, and exterior envelope systems that are functional and aesthetic features of
the Solar Decathlon entry. We provided recommendations for the three systems and
included a Gantt chart outlining production and delivery schedules. We fulfilled our goal
by addressing the following research objectives:

1. Learn about the production process and technical details of zellige, leather, and
   wicker.
2. Provide a specification sheet with pictures of zellige, leather, and wicker for Team
   OCULUS.
3. Determine the best options for the flooring, insulation, and exterior envelope
   systems.

Objective one consisted of initial data collection while objectives two and three
included the organization and analysis of collected data.

To learn about the production process and technical details of zellige, leather,
and wicker, we used three methods while collecting data. One method we used was
observing the artisans to get an idea of their craft and methods. The second method we
used was conducting interviews since they allowed us to learn how the artisans will
construct the features we have planned for the house. Each interviewee was asked if they
agreed to have their work or workspace photographed. If they declined, we defaulted
solely to note taking. The last method we used was shadowing the artisans while they
worked which allowed us to visually observe their work. We targeted experienced
artisans for our interviews because of their expertise in their specific trade.

To provide specification sheets with pictures of zellige, leather, and wicker for
Team OCULUS, we compiled the information from the interviews into specification
sheets. The sheets contained technical and descriptive information on the possible
variations of zellige flooring, leather insulation, and wicker envelope. These
specification sheets will be provided to the Team OCULUS Design Group, so they can
make an informed decision on each of the house features.

To determine the best options for the flooring, insulation, and exterior envelope
systems, we performed a ranked analysis. This analysis focused on the different options
available for each of the three house features and determined which would work well
with the house. We used the design considerations shown in Table 1 as evaluation
criteria for the ranked analysis. Because some criteria were more important than others,
we weighed each one on a scale of 0 to 3. Weights of 0 imply that either a criteria did not
apply to a particular
Based on the findings, we recommended that:

1. **Team OCULUS use zellige square tiles for the flooring system of the house.**
2. **Team OCULUS use sheepskin leather for the leather pouf insulation system.**
3. **Team OCULUS use split laurel tree wood for the exterior envelope system.**

In the ranked analysis, square zellige tiles scored highest in the raw and weighted scores. The main factor when deciding this was the weight of each individual piece. The smaller square zellige pieces will be easier to carry and transport. The construction of the floor is estimated to take one month, so the initial design phase should start in the beginning of March. Construction should start in the middle of April to allow for enough time for it to be assembled and shipped to the project site. A Moresque craftsman will have to be hired to assist in the final assembly at the project site in Benguerir.

For leather, sheepskin has the highest weighted score. Weight was one of the deciding factors as the leather poufs will add dead weight to the structure. Sheepskin is

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**Table 1: Evaluation criteria weights for the three crafts**

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<td>Aesthetics</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Assembly/Disassembly</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
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<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cultural Considerations</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sustainability</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maintenance</td>
<td>1</td>
<td>1</td>
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<td>Materials</td>
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<tr>
<td>Production Time</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Shipping</td>
<td>2</td>
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<td>2</td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
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</tr>
<tr>
<td>Weight</td>
<td>3</td>
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Our recommendations from the artisanal crafts that had higher weighted scores.
one of the lightest types of leather and will not add much weight. One option for the source of leather poufs is the Craftsman’s House located in Rabat. They have the ability to produce up to 40 poufs in a week, so they would be able to create the number of poufs needed quickly. The craftsmen should be contacted no later than the middle of March to begin the design. Production should begin no later than April to ensure that they are completed by the end of June.

Split laurel wood wicker scored the highest in the ranked analysis. Traditional bamboo wicker was a close second, but the deciding factor for split laurel wood wicker was its flexibility. Bamboo is too rigid to bend easily, whereas the split laurel wood is flexible and allows for more curvature. Since the artisan we recommend using, Mr. Abdullah, works by himself, we propose that he should be contacted early in March to begin design. Construction will take about one month, so it should start no later than the middle of May. This will ensure that it is complete by the middle of June.

From these recommendations, we submitted a Gantt chart to Team OCULUS, shown in Figure 3. The Gantt chart outlines the specific dates regarding craft commission and shipping time to both ENSAM and the building site. A Gantt chart will aid Team OCULUS so they can make the final decision on when and how the artisans will incorporate zellige, leather, and wicker into the house.

![Gantt chart](image-source-illustration.png)

*Figure 3: Gantt chart showing schedule for design, construction, and shipping. Image source: Dakota Payette*

We are pleased to offer our findings and recommendations to Team OCULUS, and are honored to have assisted the MQP teams and collaborating universities on their Solar Decathlon Africa house design.
1.0 Introduction

The Solar Decathlon is a competition sponsored by the U.S. Department of Energy that challenges collegiate teams to design and create innovative and net-zero energy solar powered homes. In September 2019, several IQP and MQP teams and faculty from Worcester Polytechnic Institute, along with two partner universities from Morocco and one from Nigeria, will compete together as Team OCULUS in the first Solar Decathlon Africa held in Benguerir, Morocco. The purpose of the competition is to incorporate aspects of past Solar Decathlons and tailor them to the needs of African communities. The goal for Team OCULUS is to create an affordable, attractive, and efficient net-zero energy geodesic-like house which incorporates multiple African and Moroccan cultural artisanal crafts. Three crafts - zellige, leather, and wicker - were chosen and incorporated into the designs of the house’s flooring, insulation system, and exterior envelope systems, respectively. Each feature had its own technical challenges when integrating the artisanal crafts into the design. Zellige is heavy, costly, and slow to produce. Leather is not typically used as insulation and may be too heavy for the structure to support. Typical bamboo wicker is not very flexible and may deteriorate in the sun and rain. Research on these technical challenges was needed, so our IQP team traveled to Rabat, Morocco to conduct research on the three artisanal crafts the MQP design team wanted to incorporate into the house features. The goal for this project was to provide our recommendations for the flooring, insulation, and exterior envelope systems that are functional and aesthetic features of the Solar Decathlon entry.

We achieved our goal through three main objectives. Our first objective was to learn about the production process and technical details of each feature. Our team connected and worked directly with local artisans to overcome challenges associated with the production, design, and physical construction of the features. We interviewed, observed, and shadowed three artisan groups - Moresque for zellige, The Craftsman’s House for leather, and Mr. Abdullah for wicker - to gather information on the production, assembly, and shipping process for each artisanal craft and house feature. For our second objective, we created specification sheets with pictures, and a Gantt chart for each feature. In our third objective, we then made our recommendations for the house features by using a ranked analyses of different criteria to determine which options would be best for the house design. We submitted our research, specification sheets, and recommendations to Team OCULUS for team leaders to finalize the designs and plan for house features.
In this chapter, we explain the history and rules of the competition, WPI’s past and current involvement in the Solar Decathlon, and the three main artisanal crafts which are to be incorporated into the final house design: zellige for flooring, leather for insulation, and wicker for the exterior envelope.

2.1 Overview of the Solar Decathlon

The Solar Decathlon is a collegiate competition run by the US Department of Energy which challenges students to design and build efficient, innovative, net-zero energy homes that rely on solar energy. The purpose of the Solar Decathlon is to provide students with specialized training that prepares them to enter the clean energy workforce and educate students and public on the latest technologies in energy efficient construction and design. (Solar Decathlon, n.d.).

The Solar Decathlon first took place in 2002 on the National Mall in Washington, DC, and has been held biennially since then with more than 150 collegiate teams and 18,000 students from around the world coming to compete in the competition. The competition has since spread internationally to Europe, China, Latin America, and the Middle East with over 160 additional teams and 19,000 students participating. The latest competition to be added and the competition that WPI will be participating in, Solar Decathlon Africa, will be held in September 2019 in Benguerir, Morocco. The goal for the Solar Decathlon Africa is to create a competition that follows the structure and philosophy of the Solar Decathlon as it is in the United States, but incorporates the unique cultural and architectural aspects of African communities (Solar Decathlon Africa, 2018). In the next section, we introduce the rules of the competition and present the criteria and contests the project will contribute to.

2.1.1 Rules and Contests of the Solar Decathlon

The basic rule of the Solar Decathlon is for teams to create net-zero solar powered, innovative, and attractive houses. While the house project has a duration of approximately two years from start to finish, teams only have three weeks to construct their house. After the construction phase, teams compete in a large competition designed to test multiple aspects of their house. The competition is split into 10 different contests: architecture, engineering and construction, market appeal, communications and social awareness, appliances, home life and entertainment, sustainability, health and comfort, electrical energy balance, and innovation. Each contest has a maximum scoring opportunity of 100 points. Contests are scored either by measuring outputs,
such as temperature and relative humidity of the house, temperature output of appliances, and electrical energy balance, or by a jury subjectively awarding point values for innovation or architecture. Awards are given out for each of the ten contests. The team with the highest combined point value wins the Solar Decathlon competition (SDA Rules, 2018).

There are two contests which the project is directly applicable to: the architecture and innovation contests will contribute indirectly to others. The architecture contest focuses on the use and integration of local, sustainable materials and designs. The innovation contest focuses on how teams have brought new ideas in concept, approach, research, design, implementation, and execution into their house (SDA Rules, 2018). Our research will provide evidence that local, sustainable materials were used when possible and that old forms of artisanal crafts were used in new ways.

**2.1.2 History of WPI in the Solar Decathlon**

In 2013, the first Solar Decathlon China was held in Datong, China. WPI partnered with two other universities, Polytechnic Institute of New York (NYU-Poly) and Ghent University in Belgium, to form Team BEMANY. The final house design, named the “Solatrium” and shown in Figure 4, included an atrium to provide high ceilings and natural lighting. The floor-to-ceiling windows and atrium allowed for passive solar heating and natural light to enter the house during the day (Freeman, 2013). The team used phase change materials which are materials that can store and release large amounts of energy from the transition between the solid and liquid phase of a material (Wahid, Hosseini, Hussen, Akeiber, Saud, & Mohammad, 2017). The combination of passive heating and cooling and the integration of phase change materials reduced the energy load on the house.

The house was first built in Worcester in collaboration with the Worcester Technical High School. Students contributed to welding, plumbing, carpentry, and electrical work. After it was assembled, it was deconstructed and shipped to China for the competition (Freeman, 2013). WPI’s participation in the Solar Decathlon China provided critical knowledge in modular composite construction and prefabricated structures which can be used for the upcoming Solar Decathlon Africa competition. For Solar Decathlon Africa, WPI will
once again construct the house at a satellite location, (ENSAM, a university Meknès), deconstruct it, and transport it to the competition site in Benguerir.

In 2019, WPI, along with three partner universities, will compete in the Solar Decathlon Africa as Team OCULUS. Two of the universities are located in Morocco, École nationale supérieure d'informatique et d'analyse des systèmes (ENSIAS) Rabat and École nationale supérieure d'arts et métiers (ENSAM) Meknès, and the third university, the African University of Science and Technology (AUST), is located in Nigeria.

They have designed a solar house with a geodetic-like structure and a focus on local, sustainable, and affordable materials. The conceptual designs for the structural envelope of the house and floor plans are shown in Figures 5 and 6. The house will be marketed for eco-tourism and used as a platform for education on net-zero energy buildings (El-Korchi & Van Dessel, 2018). It features flexible indoor space with moveable sleeping pods for maximum flexibility (El-Korchi & Van Dessel, 2018). The team plans to use evaporative cooling to control the temperature, which reduces energy draw to cool the house. They also plan to incorporate local Moroccan crafts in the interior and exterior design such as zellige for the floor system, leather for insulation bags for the walls, and wicker for the exterior envelope.

2.2 House Features

The designs for the flooring, insulation, and exterior envelope of the house are heavily dependent on the artisanal crafts they incorporate. Zellige, leather, and wicker have unique histories, materials, and production methods, so the featured designs must consider the different cultural and technical challenges posed by these crafts. Zellige tiling historically follows an artistic design of storytelling and abstract meanings, but its
intricacy relates to a costly and slow manufacturing process and difficulties with specialty workmanship, cost, and time. Leather can be incorporated into the wall system by using natural, sustainable, and fireproof materials in poufs or pillows; although, it may be difficult to use with insulation and walling because of the combined weight. Wicker would make an attractive exterior, but it may not be able to hold up to long-term sun and rain exposure unless there is an application of a protective finish. Addressing these concerns is important to assuring that the house both functions properly and portrays aspects the Moroccan culture. In the following sections, we further discuss the history, production methods, and specific design considerations and technical challenges for the crafts associated with the house features.

### 2.2.1 Zellige

Zellige is a popular ancient Islamic art form used in much of Moroccan design and architecture that dates back to the tenth century. The name zellige itself comes from Arabic, meaning ‘little polished stone.’ It is believed that its original purpose was to produce a work similar to the Greco-Roman mosaics, shown in Figure 7, without representing living creatures or people which is forbidden in the Islamic culture (A., 2017).

Thus, much of Moroccan tilework features heavily on patterns that have an endless amount of geometric combinations, embellishments, and colors. When the tiles were first created, they were mainly brown and white. As the technique expanded through the 14th century and into the 17th century, more colors were integrated to decorate palaces, fountains, patios, and other architectural structures. Colored mosaics traditionally represented the four elements fire, water, air, and earth with saffron, blue, black, and green respectively. Other designers used black, white, and brown to represent the spirit, red for dry and hot fire, blue for the dry and cold earth, yellow for hot and moist air, and green for cold and moist water. The meanings of the colors have evolved over time to depict various stories and cultural aspects (A., 2017). Mathematics also plays a role in this visual artistry as well, as seen in the repeating interlaced and tessellated honeycomb and checker patterns (Zellij - The Prince of Tiles History | Zellij Gallery, 2017). Zellige tiles can be incorporated into various forms of architecture, ranging from wall and floor designs to fountains and tables which are shown in Figures 8 and 9.
Zellige is a mosaic tilework technique made and assembled from uniquely and individually chiseled geometric tiles. The production begins with the gathering of soil from mountains located in Fes, Morocco. This soil is soaked in water until it reaches a soft texture. Then, craftsmen take the clay and flatten it by hand into square shapes making sure to make it as compact as possible with no air bubbles. After the clay is shaped, molded, and flattened, it is stored in a cool place until it is ready to be baked. After the first round of drying, various types of chemicals and dyes are applied to the tiles to color it. Then, the tiles are baked in natural wood-fired kilns. Traditional Moroccan kilns have heat that circulates unevenly throughout the oven so that each 12x12 cm tile has a unique and slightly different tone of color during the second round of baking (M, n.d.). The dried tiles are then cut into a desired shape, some popular ones being stars, crosses, and octagons. This process takes at least three sets of craftsmen. The first craftsman selects the tile and draws a desired shape. The second cuts excess tile to get to a rough outline of the desired shape with a menkach, which looks like a combination of an axe and hammer. The third applies precise cutting techniques, finalizing the intricacies of the exact shapes that will be assembled together in a specific pattern (M., n.d.).

Once the tiles are laid out, they are pieced into a frame to ensure equal dimensions are filled. The zellige pieces are assembled into these frames by hand and cement or plaster is poured over it to glue the pieces together. After at least 24 hours once the glue is completely dried, each large frame is glued to other frames to form the complete mosaic tile (M., n.d.).

A design consideration when incorporating the flooring system into the house was how feasible it would be for the zellige artists to build the tiles in a way such that it would be easily shipped to ENSAM and the final competition build site in Benguerir. Another aspect to using zellige as the flooring system is the production time. Due to the time-consuming process of this technique, having to construct tiles to cover a large
surface area would take a substantial amount of labor and a large enough group of commissioned artisans.

**2.2.2 Leather**

Leather is another cultural feature our group wanted to predominantly showcase in the house for the insulation method. The production of Moroccan leather dates back to the time of the Roman Empire. The technique was first used by the Greeks but was later implemented into the Roman society. When the city of Fes was founded in the mid-8th century, it quickly became the epicenter for leather production with three tanneries in the medina. The oldest and largest tannery in Fes, Chouara Tannery, is shown in Figure 10 (Kaushik 2014).

The production of leather at the tannery has remained relatively unchanged since it was founded. Since craftsmen tend to use little modern machinery, most products are handmade. There are nearby factories, however, that rely on modern machinery to aid with the production. As described in Kaushik (2014), production starts by dipping four different types of animal skins, skins of sheep, goats, cows, and camels, into a water basin. The water basins are filled with a mixture of cow urine, quicklime, water, and salt, which helps break down the toughness of the skin and wick away dead skin cells, extra fat buildup, and hair follicles. Once the skins have lost most of their rigidness and all hair follicles, they are put into colorful water. These water basins are filled with various naturally occurring colored dyes, such as red from a poppy flower, blue from indigo, orange from henna, brown from cedar wood, green from mint, and yellow from saffron (Kaushik 2014).

In order for the skins to cure and take on the color of the dye, craftsmen soak them in the mixture for two to three days. After the curing process, the skins are taken out of the basins to air dry. The smaller skins are laid flat on the ground to dry, while the larger skins are hung up to dry. The larger skins are also the ones that take longer to dry. Air drying the skins allows for the smell of the mixture to wick away, but an odor lingers once fully dried. Chemicals are applied to the leather to mask the odor, but the price
increases. Once the leather has dried, the skins are ready to be shaped, molded, and sewed into various products (Kaushik 2014).

Leather products can be used for a multitude of applications, including but not limited to jackets, personal bags and purses, shows, belts, wallets, and poufs. Since the project focused on the use of poufs as an insulation source, we looked into how they are made and the technical challenges surrounding them. The most common shapes for poufs are circles and saddles. Craftsmen use stencils and cutouts to replicate the shapes by hand. Cutting shapes out of the leather, however, leaves behind leftover material, but the tanneries put it to use. Most of the leftover material is reused for smaller parts in production, such as inlay designs on larger pieces, as seams for holding multiple pieces of leather together, or as straps for bags.

Modern leather factories typically ship in plastic to use as seams for holding multiple pieces together, but the tanneries use leftover leather scraps. Leather bound seams are more durable than plastic seams because plastic tends to chip and crack under regular use. String coated in beeswax is used as the stitching to add flexibility and reduce the possibility of snagging. By hand, craftsmen add rope between the seams to provide a rounded edge. Craftsman also add glue, made from natural materials, spices, and powders, to the seams to strengthen them. There is an abundant supply of leftover material available to work with, but craftsmen attempt to use as little as possible.

Once a product is complete, a coating of oil is applied to the exterior leather. The oil adds a darker and shinier appear to the product. In addition, the oil protects the product from water and fire since oil is hydrophobic and will not catch on fire once dried. Fire protection was a key element our group wanted to have for the poufs.

### 2.2.3 Wicker

Wicker is the process of weaving a fibrous or cane-like material to form one cohesive structure. A large wicker envelope will comprise the facade of the house, serving as an attractive aesthetic feature and an environmental shield. Wicker crafts became popular in Morocco many centuries ago because of the native prevalence of bamboo and rattan plants (“History of Moroccan wicker baskets,” 2016); (“Rattan facts and information,” 2010). Bamboo and rattan wicker are preferred for their ease of formation, sturdy structure, and natural wood-like texture. Other wicker materials include willow, reed, cane, straw, and palm leaves. Furniture and handicrafts are the primary Moroccan wicker products, but some limited uses also exist in building construction; in either case, they are a principal defining feature of the Moroccan home and culture.
The wicker weaving process follows an ancient traditional technique that has largely remained unchanged over the years. The minimum tools required for weaving are a knife, a saw, and a flat plane, but some artisans use custom-made tools that are specifically designed for a certain material or product. In the first step of this process, the artisan dries out the chosen material to give it a uniform texture and make it more pliable. Once dried, the material is split into thin strands which are braided as shown in Figure 11. The braiding continues until the thin strands form thicker belts that can then be woven for different features.

The artisan may choose not to thin out and braid the material if they desire a coarser finish for the product. At this point, the artisan can begin combining the strands/belts to create the object they are making. In Figure 12, an artisan is creating a large wicker basket through this technique. Longer, thicker strands of material are bent such that they form the shape of the basket and act as a support structure, while the smaller strands are interlaced between them to form the main body.

Wicker alone does not always provide the desired properties for a given application. While most wicker materials have excellent tensile strength, some perform poorly under a compressive load. Artisans overcome this by creating composite structures of wicker and wood that exhibit the best properties of both. As shown in Figure 13, an artisan applies this technique to create a traditional Moroccan stool by wrapping a wicker body around a wooden backbone (Locale, 2016). The wooden structure provides a rigid foundation that handles well under compression, while the wicker is positioned such that it faces only a tensile load.
Some material properties of natural wicker are challenging to design around due to its interactions with the environment. Most wicker products are restricted to indoor applications due to rattan’s poor resistance to rain and sun. Rattan is an inherently porous material, which enables water to absorb into it and may cause warping or rotting. It is also susceptible to prolonged UV exposure, which dries out and discolors the rattan. Rattan is mainly used for nonstructural applications such as hunts or animals pens instead of as long-term structures because it requires frequent maintenance. For such applications requiring wicker with decent long-term durability, many artisans opt to use bamboo or wood in place of rattan. Bamboo and wood are significantly more resistant to environmental damage and can support a higher structural load, meaning less degradation or physical damage over time. Artisans and manufacturers that produce wicker will occasionally apply some protective coating(s) to further increase durability, but the exact substances used vary between sources and they must be reapplied periodically to maintain their effect.

2.3 Moroccan Craft Groups and Artisans

The production of the flooring, insulation system, and exterior envelope of the house will be handled by three artisanal craft groups in Morocco. Moresque from Fes is responsible for the zellige tiling that will be incorporated into the flooring system of the OCULUS house. The Craftsman’s House in Rabat will produce the leather poufs that will be incorporated into the insulation system of the house. The wicker envelope will be constructed by an independent artisan in Skhirat named Mr. Abdullah Idrissi.
2.3.1 Moresque

Moresque is the largest of the organizations that we have commissioned for production of a house feature. Located in Fes, Morocco, they are an artisanal craft group that specializes in zellige, plaster, wood, and brass. Their mission, as stated on their website, is to “preserve, protect, and promote Islamic Architectural Heritage” through the Moroccan art they produce (Moresque, 2017). Moresque was founded in 1928 by the master artisan Mohammed Telmsani Eissaoui (Moresque, 2017). The company first began with ten employees, which included half a dozen skilled artisans and a couple of apprentices. Over time, the company has grown to take on noteworthy projects, such as the King’s palace, which has allowed their reputation to grow. Now, Moresque is widely known for their work in many palaces, hotels, and restaurants, and is accredited in the U.S. for their work in the Metropolitan Museum of Art in New York City. Their exhibit in the museum is shown in Figure 14 (Kennedy, 2011).

2.3.2 The Craftsman’s House

The Craftsman’s House is a collaboration of artisans located just outside of the Rabat medina. The center specializes in a multitude of artisanal crafts, with the most notable being the production of leather poufs. The Craftsman’s House purchases large leather sheets from Fes and uses it to create the poufs that are sold widely in the medina and elsewhere.

2.3.3 Mr. Abdullah Idrissi

Mr. Abdullah Idrissi is an independent artisan running a small business out of the seaside town of Skhirat. He is a lifelong expert in the wicker trade, having begun his work after learning the craft from his father. His outdoor facility is efficient and practical, containing an open field to do his work and an enclosed place to store finished products. Mr. Abdullah Idrissi sources his materials from the bamboo stalks and laurel shrubs that grow wild near his workplace.
WPI will be competing in the Solar Decathlon Africa competition to be held in Ben Guerir, Morocco in September 2019. They are designing a geodesic-like house that can be used for eco-tourism and incorporates Moroccan artisanal crafts into the flooring, insulation system, and exterior envelope. Zellige, leather, and wicker, which will be used for these features, each have their own history, production methods, and technical challenges associated with them. We worked with different craft groups and artisans to incorporate these crafts into the house. In the next chapter, we introduce the project goal and the process by which we achieved this goal.
The goal for this project is to provide our recommendations for the floor, insulation, and exterior envelope features identified as functional and aesthetic of the Solar Decathlon entry. The competition will begin on September 13th, 2019, but on-site construction of the house will begin on August 20th. Before the start of the official competition, the house will be constructed and deconstructed at Ecole Nationale Supérieure des Arts et Métiers (ENSAM) in Meknes and relocated to Benguerir on August 10th. In order to construct the house at ENSAM Meknes before the full assembly for the competition, all house features and raw materials must be delivered before July 20, 2019. Our recommendations included a Gantt chart which outlined when design and construction needs to start and when the features will be shipped. We fulfilled our goal by addressing the following research objectives:

1. Learn about the production process and technical details of zellige, leather, and wicker
2. Provide specification sheets with pictures of zellige, leather, and wicker for Team OCULUS
3. Determine the best options for the flooring, insulation, and exterior envelope systems

Our objectives are organized in the order of when they occurred in the project timeline. Objective one comprises of initial data collection while objectives two and three consist of the organization and analysis of collected data. In the following sections, we discuss the methods used to achieve these goals.

3.1 Objective 1: Learn about the Production, Shipping, And Assembly Details for Zellige, Leather, and Wicker

The design teams for the Solar Decathlon house and the project advisors identified three areas where artisanal crafts would be incorporated into the house design: zellige tiling for the flooring system, leather poufs to act as bags for insulation, and wicker for the exterior envelope. With these features identified, we needed a professional opinion on how they might be incorporated, the different options for each feature, and technical details specific to the project. Therefore, we were introduced to skilled craftsmen by our sponsors and began to work with them on each feature.

We used three methods while collecting data. One method we used was observing the artisans to gain an understanding of standard craft materials and methods. The second method we used was conducting interviews since they allowed us to learn how
the artisans will construct the features we have planned for the house. The last method we used was shadowing the artisans while they worked which allowed us to visually observe and validate the interview results. We targeted experienced artisans for our interviews because of their expertise in their specific trade. We have identified three artisanal craft groups which are introduced in Section 2.3 of the Background.

Data that was recorded during the interview process was primarily done through note-taking and pictures. Each interviewee was asked if they agreed to have their work or workspace photographed. If they declined, we defaulted solely to note taking. One issue we faced while conducting interviews was the language barrier, which we addressed by using a translator to conduct some of our interviews. From the interviews and shadowing, we compiled a list of the production methods, possible applications, required materials, material cost, and sustainability of each craft.

3.2 Objective 2: Create Specification Sheets with Pictures for Zellige, Leather, and Wicker

With the data we collected from the artisan groups, we compiled specification sheets that contained technical and descriptive information on the different possible variations of zellige flooring, leather insulation, and wicker envelope. These specification sheets served as an efficient way to organize our gathered data and could be used as a quick reference guide for the specific details of each craft. The data in the specification sheets was organized based on the design considerations that were relevant to a certain feature, as detailed in Table 2.

Some design considerations did not apply to every feature because either we did not have any control over that aspect or it had no effect on our research. Even though the average cost for zellige flooring

<table>
<thead>
<tr>
<th>Design Considerations</th>
<th>Zellige</th>
<th>Leather</th>
<th>Wicker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Assembly/Disassembly</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Cost</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Cultural Considerations</td>
<td>✔️</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Materials</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Production Time</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Shipping</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Size</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Sustainability</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Weight</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
would be 2000 to 4000 Dirham ($210 to $420 USD) per meter square, we knew ahead of time that the zellige flooring would be provided to Team Oculus free of cost. As for the information that was relevant, we used this structure to identify any holes in our data where more research would need to be done. In one case, we found that we had not recorded all of the sizing information that we needed for leather, so we referred back to the methods in Objective 1 to solve this problem. Once the specification sheets were written, we could begin analyzing the data to decide the best option for each feature in the house.

### 3.3 Objective 3: Determine Best Approaches for House Features

With the information from the specification sheets of zellige, leather, and wicker, we performed a ranked analysis. This analysis focused on the different options available for each of the three house features and determined which options would work well with the house. We used the design considerations shown in Table 1 (Section 3.2) as evaluation criteria for the ranked analysis.

To rank the feature options, we assigned a value of 1 through 5 to the options based upon how well they addressed the justifications under the criteria. A score of 1 was the worst score while 5 was the best. The justifications of each evaluation criteria are shown in Table 3.

*Table 3: Evaluation criteria justifications*

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Justifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aesthetics</em></td>
<td>Visual appeal of finished product relative to the theme of the house</td>
</tr>
<tr>
<td><em>Assembly/Disassembly</em></td>
<td>Ease of installation and ability to be taken apart and reused</td>
</tr>
<tr>
<td><em>Cost</em></td>
<td>The manufacturing, material, and/or shipping costs</td>
</tr>
<tr>
<td><em>Cultural Considerations</em></td>
<td>How well a design style represents the Moroccan culture</td>
</tr>
<tr>
<td><em>Maintenance</em></td>
<td>The long-term requirements for upkeep, including cleaning and repair</td>
</tr>
<tr>
<td><em>Materials</em></td>
<td>The specific materials used and any applicable treatment process(es)</td>
</tr>
<tr>
<td><em>Production Time</em></td>
<td>The time required to manufacture the feature</td>
</tr>
<tr>
<td><em>Shipping</em></td>
<td>Ease of transporting to the construction sites at ENSAM and Benguerir</td>
</tr>
<tr>
<td>Size</td>
<td>The minimum area or volume required or the maximum achievable</td>
</tr>
<tr>
<td>--------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Sustainability</td>
<td>The environmental impact of production</td>
</tr>
<tr>
<td>Weight</td>
<td>The weight of a product and how it impacts structural design</td>
</tr>
</tbody>
</table>

Because some criteria were more important than others, we weighted each one on a scale of 0-3 as shown in Table 4. We created the weights based upon the needs of Team OCULUS and how each artisanal craft will affect the house. Weights of 3 signified the highest importance, while weights of 0 imply that either a criteria did not apply to a particular feature or the result would be identical across every option we compared.

The criteria scores in our ranked analysis resulted in two key values for each option: a raw score and a weighted score. The raw score is a summation of all the individual criteria scores for an option and represents how well the option addresses the criteria as a whole. The weighted score accounts for the importance of each criteria by multiplying the criteria score with the criteria weighting. We used the raw and weighted scores to guide our recommendations for the house features.

We also submitted a Gantt chart to Team OCULUS. The Gantt chart outlines the specific dates for design evaluation, craft commission, and shipping time to both ENSAM and the building site. A Gantt chart will aid Team OCULUS so they can make the final decision on when and how the artisans will incorporate zellige, leather, and wicker into the house.

Table 4: Evaluation criteria weights

<table>
<thead>
<tr>
<th>Evaluation Criteria Weights</th>
<th>Zellige</th>
<th>Leather</th>
<th>Wicker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetics</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Assembly/Disassembly</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Cost</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cultural Considerations</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Materials</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Production Time</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Shipping</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Sustainability</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Weight</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
3.4 Summary of Methodology

The overall goal of the project is to provide our recommendations for the floor, insulation, and exterior envelope features identified as functional and aesthetic of the Solar Decathlon entry. We achieved this goal through three main objectives. In the first objective, we learned about the production process and technical details of the three crafts through interviewing, observing, and shadowing artisans. The second objective was to provide a specification sheet for the Team OCULUS Design Group by compiling the data from the interviews with artisans. Our third objective was to determine the best option for each house feature which we achieved through a ranked analysis. Next, we will present our findings from our interviews, specification sheets, and ranked analysis.
In this chapter, we discuss the results of our interviews with various craftsmen and detail the observations we made while shadowing them as they worked. The results are divided into sections describing the production, shipping, and assembly processes of zellige, leather, and wicker, culminating with the specification sheets and the ranked analysis for each craft.

4.1 Zellige

Zellige will be incorporated into the flooring system of the house design. Our zellige contact was a well-known family-run business called Moresque located in the Fes area. On two separate occasions we toured one of their smaller workshops in the city and their production center located in the mountains. The visits provided our group with information regarding the zellige tile floor that will be used in the house.

4.1.1 Production Process of Zellige

We took notes and pictures during our visit to Moresque to learn about the production process of zellige. Moresque starts the production process of zellige with extracting Kaolinite clay from the mountains outside of Fes (El Ouhabi, Daoudi, & Fagel, 2014). The clay is transported to the processing location in the valley of one of the mountains. There, the clay is soaked in pools of water for three to four days to allow the hard clay to soften. The clay is then taken out of the pools and put into the sun for one to two days for excess water to evaporate. Both the mound of clay and the soaking pools (shown in Figure 15A). From there, the clay is molded into rectangles to sun-dry (shown in Figure 15B). Then, the clay is further shaped into 10x10cm squares (shown in Figure 15C) and laid out to dry in the sun for
two days in the colder months and one day in the summer (shown in Figure 15D). Once they are hard enough to handle, the squares are stacked in the one of two large ovens (shown in Figure 15E) for baking with the temperature set at 900°C. Each oven can hold up to 10,000 squares, which is 100 m² of tile. Instead of using coal or wood to fuel the flames of the oven, craftsmen use olive pulp, a by-oil production, in an effort to reduce their carbon footprint. After baking the tiles through the oven, they are taken out and dipped into different color basins depending on what the client wants (shown in Figure 15F). The client can choose from premade colors or can request the artisan to create a specific color (shown in Figure 15H). The colored tiles must be baked again in the oven (shown in Figure 15G) to determine what the finished product will look like. Since color variations can occur based upon how long the tiles are in the oven, test samples are put into the oven before the client approves of a final color.

The total time of production from gathering the clay in the mountains to taking them out of the second oven ranges from eight to ten days depending on how long the clay soaks in the water and how long it needs to dry in the sun for. Once tiles have been shaped and baked, they are shipped to their workshop in the city.

Moresque recently converted their traditional wood- and coal-firing ovens to gas and biomass, in coordination with efforts by the city of Fes and other artisan groups to reduce the impact of air pollution. To further reduce pollution, they also moved the bulk of raw production out of the city and into the mountains. However, the facilities responsible for tile assembly still remain inside the city of Fes.

Assembly of a zellige floor or wall can take anywhere from one week to three months to complete depending on the size and complexity of the design and the number of people working on it. Simpler designs with larger tiles are the easiest and quickest to assemble, whereas a complex design with smaller tiles take more time and skill to chisel down and assemble. In one example, a highly complex wall mosaic featured in Moresque’s workshop had an area of 13m² and took one month for a team of ten men to
complete. Most zellige assemblies use a combination of both simple and complex designs for a better balance of production time and aesthetic.

Moresque assembles many floors with lightweight and modular tiles that fit together as puzzle pieces. The mosaic designs are first drawn up digitally in a modeling program to specify exact dimensions and orientation of each tile. Designs tend to reuse the same tiles in different orientations because it is quicker and easier to mass produce copies of tiles than to produce new custom shapes. The design drawing is then printed out and a craftsman will use it to guide the construction of the mosaic. Zellige tiles are assembled face-down on the ground as shown in Figure 16, with the craftsman only seeing the rough, unfinished side of the tiles. Although the back sides of the tiles are all the same grey color, an artisan can differentiate between them because every unique shape will only have one possible color on the front. With the tiles arranged face-down, a thin coating of cement is then applied to the backside to bond the assembly together. Once dried, the zellige assembly can then be flipped over to reveal the completed design on the front, as shown in Figure 17.

The standalone weight for one square meter of tiles with cement is 17 kg. During installation, a bonding agent is added to the backside of the tiles to hold them in place, which raised the weight of one square meter of tiles to 20 kg. Given that the floor of the house has a total area of 78.5 square meters, the entire zellige assembly would have a weight of approximately 1.6 tons. The tiles are preassembled in the workshop and put into a larger modular design that can be easily transported.
Designs are typically symmetrical and influenced by aesthetics of the overall shape of the floor. Clients can select from available patterns on different geometric designs that can be used. For the geodesic-like house that Team OCULUS has designed, the plan for the floor is to create 12 individual but identical wedges made from the modular tiles, which is shown in floor renderings in Figures 5 and 6 from Section 2.1.2: WPI in the Solar Decathlon.

If wedges were to be created for the house design, the wedges would consist of large interlocking tiles with an intricate circular centerpiece. The border of each wedge would be created by individual edge pieces which stopped the design from entering the next wedge. An idea proposed by the Team OCULUS Design Group was to add marble or metal inlays which would add more separation between each wedge. Another option is a floor made of smaller square zellige tiles where pieces that line the perimeter of the circular floor plan has rounded edge. Team OCULUS has also expressed interest in hardwood floors with zellige tiles, which would provide some aesthetic contrast to the zellige. With a weight of 8 to 13 kg per square meter depending on the material (“Taking delivery of your hardwood flooring”, n.d.), the hardwood floor would be much lighter and much easier to handle than zellige. Moresque does not offer hardwood floors, so this type of flooring would have to be sourced elsewhere.

4.1.2 Shipping Process of Floor Tiles

Shipping options were determined based upon the construction of the tile options. Since the tiles are lightweight and modular, they pack well into small spaces and can be shipped by using a pick-up truck, which may be less costly than a larger moving truck. The tiles need to be individually wrapped, boxed, or tied to prevent cracking while in transit. If not properly wrapped, tiles will scrape against one another and break. The total weight of the tiles should also be taken into consideration since there are weight limits for different modes of transportation. By shipping the wedges using a truck, the wedges can be transported from Fes to Benguerir in a day since the average travel time between the two cities is five hours. Moresque has their own shipping company they employ to transport finished products from their workshop.

4.1.3 Assembly Process of the Floor Tiles

During the floor assembly of the Solar Decathlon house, an issue that presented itself with zellige wedges is that they can only be assembled on the floor once. Moving the wedges too many times increases the risk of tiles chipping. The flooring cannot be installed along with the rest of the house at ENSAM before the competition. The only time the flooring can be assembled is during the construction phase of the competition at Benguerir. To work around the installation issue, a replica floor will be constructed at
ENSAM. The replica floor will have the same thickness, 10 cm, and weight as the zellige floor. To determine where piping and electrical wires come out from underneath the floor, holes will be marked on the replica floor. The holes will then be marked and drilled into specific wedges for an easy installation during the construction at Benguerir. Once the pipes and wires are fitted through the holes on the wedges, cement will be added to close up gaps.

A specialized craftsman who understands the assembly of zellige flooring will need to be present for the final construction of the house. The students building the floor do not have prior experience in handling complex assemblies of zellige flooring which runs the risk of accidentally broken wedges. Therefore, the craftsman will be there to assist the students in assembling the zellige floor and connecting it to the frame that rests on the concrete slab. Zellige floor installations are usually meant to be permanent, so disassembly will have to be discussed with the craftsman and members of Team OCULUS to determine what will happen to the floor after the competition. These considerations will be taken into account in the ranked analysis of the various flooring options, which will be discussed in the following section.

### 4.1.4 Ranked Analysis of Zellige

We identified four options for the ranked analysis of zellige. The first option is zellige tiles shaped into wedges. The second option is zellige shaped into smaller, 30 x 30 cm square, interlocking tiles. The third option is a hardwood floor with a zellige element in the center of the floor. Moresque is unable to make hardwood flooring, but Team OCULUS could source their own hardwood flooring to go with a smaller zellige piece made by Moresque. This could lower production time as well as make assembly easier. The fourth option is a zellige floor with marble sections either separating the wedges or around the outside of the floor. These options were compared in a weighted ranked analysis as defined in Section 3.3 of the Methodology. Table 1 shows the scores for each of the categories within the evaluation criteria of the four floor design options.
Table 5: Ranked analysis results for zellige

<table>
<thead>
<tr>
<th>Options</th>
<th>Weight</th>
<th>Zellige wedges</th>
<th>Square zellige tiles</th>
<th>Zellige with hardwood</th>
<th>Zellige with marble</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aesthetics</strong></td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td><strong>Assembly/Disassembly</strong></td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td><strong>Cultural Considerations</strong></td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><strong>Sustainability</strong></td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Production Time</strong></td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Shipping</strong></td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Size</strong></td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>RAW SCORE</strong></td>
<td>36</td>
<td>38</td>
<td>33</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>WEIGHTED SCORE</strong></td>
<td>85</td>
<td>89</td>
<td>76</td>
<td>64</td>
<td></td>
</tr>
</tbody>
</table>

Each criteria were given a weight on a scale of 0-3 based on the importance of this criteria to the house feature. Criteria that were weighted with a 1 are least important while those weighted with a 3 are most important, and those weighted with a 0 were not considered during the evaluation. For zellige, there were three categories which were weighted with a 3: weight, assembly/disassembly, and aesthetics. Weight is an important consideration because it affects everything from shipping to assembly. Of the four options, square zellige tiles scored the highest because they are smaller and will be lighter than large zellige wedges or zellige with marble. Assembly and disassembly is another important factor because the floor has to be easy enough for a team of students and one professional to assemble. For this criteria, zellige with marble would be the easiest while zellige with hardwood is second since there is more prefabricated material that could easily be put into the flooring system. With the zellige wedges, it would be easier to assemble individual wedges together instead of multiple square zellige tiles. The square tiles would require more concentration on the intricacy of the full floor design, so they were ranked last. In terms of aesthetics, the zellige wedges and square tiles ranked the highest compared to the incorporation of the hardwood and marble since just zellige would have a more consistent look.

There were a number of criteria that we weighted with a 2 because they were important to consider, but not as critical as the weight, assembly/disassembly, and
aesthetics. The sustainability is important to consider for the competition, but is not a deciding factor for the flooring. Zellige with marble ranked the lowest due to the energy-intensive and pollution producing mining process for marble. The two simple zellige options and zellige with hardwood scored the same. However, when considering hardwood, it highly depends on how and where the wood will be sourced. For shipping the different materials, it would be most expensive to ship marble since it would weigh the most in comparison to zellige and hardwood, with weights given in Section 4.1.1: Production Process of Zellige. In terms of cultural considerations, plain zellige tiling would showcase Moroccan culture the best, giving it the highest score. Hardwood and marble are not traditionally used in Moroccan flooring, so they received lower scores.

The three criteria weighted the lowest were materials, maintenance, and cost. These are criteria that need to be considered but are not deciding factors. The main criteria that we focused on with a weight of 1 was the cost. Moresque is donating the flooring to Team OCULUS, so the cost will be covered for the zellige and marble. However, if Team OCULUS decided on incorporating hardwood floors, then they will have to be sourced outside of Moresque and will cost money. Therefore, zellige with hardwood was ranked lowest while the rest were ranked highest.

In the end, the highest raw and weighted score went to the square zellige tiles. The scored options decreased after that from zellige wedges, zellige with hardwood, and then to zellige with marble. The next feature that we analyzed was the leather insulation system.

4.2 Leather

Leather will be incorporated into the insulation system of the house design. One of our leather contacts is located in Rabat in a workshop called The Craftsman’s House where multiple craftsmen come together to work. Our visit to the workshop provided information regarding the technical details of the leather poufs that may be used in the insulation system of the house. We also visited a leather artisan in Fes who provided more information on the different types of leather and the process of making them.

4.2.1 Production Process of Leather Poufs

Moroccan leather comes from the skin of one of four animals: sheep, goat, cow, or camel. Sheep leather is extremely common, fairly cheap, and has a soft texture. Goat leather has a similar soft texture to sheep while being more pliable but more expensive. Cow leather is thick, strong, and rigid, with a price lower than sheep and goat. Camel leather is the least common of the four, performing similar to cow but rougher and more expensive. Most leather is sourced from the tanneries in Fes and can be dyed with
natural colors (shown in Figure 18A). The strength of leather odor inversely relates to how thoroughly it is washed with water. Leather with less odor costs more due to increased washing. The leather is hung out to dry, (shown in Figure 18B), before being handled. Natural and synthetic oils can be applied to darken the color and provide some water protection (shown in Figure 18C).

The cost to make a leather pouf is dependent upon the amount of leather and sewing required along with the complexity of designs on the leather. The walls of the house have an inside surface area of about 100m², or a real area closer to 80m² when accounting for the space occupied by the geodesic-like support structure. Since the poufs will be double-sided with a depth of 15cm, the total leather area will be in excess of 200m². Leather can be cut to any shape or size (shown in Figure 18D), such as the triangular sections required for the house, but multiple pieces must be sewn together if the desired size exceeds that of a single sheet (shown in Figure 18E). Designs are printed on the leather by using a metal stamp that is pressed firmly onto the surface (shown in Figures 18F and 18G). A thick fabric sheet is attached to the underside of the leather to provide extra rigidity to the structure. When completed, the underside of the leather becomes the inside portion of the pouf. Once stamped and reinforced, the top, bottom, and side leather pieces are joined with a combination of glue and sewing to produce a pouf (shown in Figure 18H). All but one seam is sewn permanently shut, with this last seam being fitted.
with a zipper to allow for the pouf to be filled or emptied as desired. The attractive side of the leather is the only part that remains visible on the completed pouf.

Pouf production is completed assembly-line-style, where each artisan in the process is responsible for one or two of the aforementioned steps. In our house design, triangular poufs for the house would be larger than usual, having side lengths ranging from 50 to 150 cm. The finished products are typically sold empty, but they can optionally come pre-stuffed with a rough, dense fabric material made from recycled blankets. Empty poufs can later be stuffed with other types of materials, including natural insulation materials like straw or wool and conventional insulation materials like fiberglass or polyurethane. The team of artisans from The Craftsman’s House can output an average of 40 leather poufs per week, but this number is only typical of a regular circular pouf with a diameter of 50 cm.

### 4.2.2 Shipping Process of Leather Poufs

Leather poufs do not pose any significant challenge with shipping. When empty, poufs are easily compressible and can conform to fit a small space. The leather is relatively soft and flexible which in turn does not require much padding material to keep it intact during shipping. Small quantities of empty poufs can easily be shipped through the regular postal service. However, larger quantities of leather poufs will require a truck to transport the heavier load.

### 4.2.3 Assembly Process of the Insulation System

At the construction site, the final assembly of the insulation system is governed by two factors: the insulation filling and the mounting points to the walls of the leather poufs. Using the built-in zipper, empty poufs can easily be filled on-site with any traditional insulation material and emptied again later during disassembly. Mounting the poufs to the walls of the house requires a retaining mechanism that can support the weight of each pouf. Adhesion is a potential option, but the chosen adhesive would have to be both strong enough to hold the weight of a pouf on the ceiling indefinitely and workable enough to allow the poufs to be intentionally removed without damage. The poufs can be directly bolted to the wall, which would require the leather to be pierced to allow bolts through, or a supportive net structure can be used to hold the poufs in place. Alternatively, the poufs can be indirectly mounted via ropes or support arms that attach to the wall and wrap around part or all of the pouf, allowing it to sit independent of the wall and easily be detached later.
We identified four different types of leather which could be used for the leather insulation bags: sheep, goat, cow, and camel leather. These four types of leather are some of the most commonly used in Morocco, so they were chosen for this project. The ranked analysis as defined in Section 3.3 of the Methodology comparing the four leathers is shown in Table 6.

One criteria, weight, was identified as the most important one for leather and was weighted with a 3. Since the leather bags will be placed along the inside wall, they will have to be light enough for the structure to support it. Sheep is the thinnest and lightest type of leather which scored the highest of the four. Goat and camel are heavier than sheep, so they scored lower. The lowest scoring type was cow because it is the thickest and heaviest type.

There were four criteria which were weighted with a 2. These criteria are materials, sustainability, cost, and aesthetics. For materials, sheep ranked the lowest while goat and camel ranked the highest. Sheep leather is flammable while the goat and camel leather are resistant to fire which is important because the leather insulation will be along the inside of the walls. In sustainability, sheep and goat scored the highest because they are common livestock animals which are used for meat. Cow was scored in the middle because while they are also livestock, large cow farms can have a negative impact on the surrounding area and produce a lot of pollution. Camel was scored the lowest because they are not used for another purpose like meat, and there are fewer of them than the other animals. The next criteria was cost. Sheep and cow are some of the most common types of leather and will not be as expensive. Camel and goat are not as common and will therefore cost more. The last criteria we measured was the aesthetic or look of the

<table>
<thead>
<tr>
<th>Options</th>
<th>Weight</th>
<th>Sheep</th>
<th>Goat</th>
<th>Cow</th>
<th>Camel</th>
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<tr>
<td>Weight</td>
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<td>3</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Cost</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Sustainability</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Materials</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Maintenance (Durability)</td>
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<td>4</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Production Time</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
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<tr>
<td>Assembly/Disassembly</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cultural Considerations</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Shipping</td>
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<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Size</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>RAW SCORE</strong></td>
<td>29</td>
<td>27</td>
<td>23</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td><strong>WEIGHTED SCORE</strong></td>
<td>54</td>
<td>51</td>
<td>39</td>
<td>33</td>
<td></td>
</tr>
</tbody>
</table>
leather. Sheep and goat leather scored highest because of their smooth texture. Cow and camel both have a wrinkled texture to them with camel leather being more noticeable, so they scored the lowest in this criteria.

Maintenance and production time were weighted with a 1 because they have the least impact on the project. Maintenance or durability judged how strong each type of leather is. Goat scored the lowest since it is soft and thin while cow scored the highest because it is strong and thick. Production time was the last criteria used for leather. Because cow and camel are much thicker leathers and not as easily sewn, they will take more time and effort to produce. Sheep and goat are thinner and easier to produce. Sheep is typically used for leather bags, so they will have the fastest production time. Size, assembly and disassembly, shipping, and cultural considerations are other important considerations, but they were weighted with a 0 in this ranking because the type of leather had little effect on these criteria.

Overall, the type of leather with the highest weighted score was sheep. Goat came in second, cow came in third, and camel came in fourth. While it was determined that sheep was the best type of leather for the insulation bags, there is another factor that must be considered for the insulation. Shape will affect the size and shipping of the leather bags. One proposed option is to create triangular shaped bags. In this case, there would have to be several sizes of triangular bag because the triangles in the structure get smaller towards the top of the house. Other options include circles or rectangles. Depending on the shape, shipping could become more difficult if the leather bags are too large. The last feature we analyzed was the wicker exterior envelope.

### 4.3 Wicker

Wicker will be incorporated into the exterior envelope system of the house design. Our wicker contact is Mr. Abdullah Idrissi, an independent artisan whose skills were passed down from his father. He runs a small business out of the seaside town of Skhirat. Mr. Abdullah Idrissi will be tasked with constructing the exterior wicker envelope that will serve as an aesthetic and protective envelope for the house. While we do have data on wicker from various other artisans in Salé and Fes, the results we outlined here largely represent the exact or extrapolated capabilities of this one artisan and the resources available to him.

#### 4.3.1 Production Process of Wicker

Wicker is a process in which various plant-based materials are woven together. The two materials our wicker contact uses are bamboo and laurel tree wood, which he sources from wild plants that grow in and around Morocco. The bamboo is green and dense when first harvested, but gradually yellows and lightens after two weeks of drying.
in the sun. The laurel wood has a greenish-brown color that remains fairly consistent over time.

The first half of wicker production involves gathering and preparing the material. The artisan harvests the bamboo stalks (Figure 19A) or laurel tree branches (Figure 19B) with a saw and takes them back to his workplace. Here, he runs a special tool called a flat plane along the length of the material to shave off the outer husk and remove imperfections, as pictured in Figure 19C. He may further smooth out the material with sandpaper if any irregularities are left behind by the flat plane. Then, he cuts the material to length with a knife like in Figure 19D and sorts the pieces by diameter. Depending on the type of weave he wants to make, he will either leave the material whole or split it lengthwise into halved or quartered strips.

The second half of wicker production involves constructing a wicker sheet. The artisan sets aside the refined materials he will use for a given project (Figure 19E) so he can quickly grab them as he needs them. To make the sheet, he first lays out the largest and strongest pieces parallel to one another to form a firm base and outline the product, as shown in Figure 19F. He then orients the remaining pieces perpendicular to the base and begins weaving them in-and-out between the openings, as shown in Figure 19G. The artisan will frequently alternate the direction of his weave - switching between going up and going down first - to apply pressure on opposing sides of the base. This technique locks
the lattice structure tightly together, preventing it from shifting around or falling apart. When completed, bamboo wicker appears as a sturdy flat sheet that requires much force to bend. On the other hand, the highly flexible laurel wood can be formed to a certain shape with a metal wire (Figure 19H) to produce curved structures.

Different wicker weave styles are available for different material sizes and applications. Whole pieces of bamboo can be used to make thick sheets of wicker with large holes in it, as shown in Figure 20. Split pieces of bamboo are used to make thinner sheets of wicker with few to no holes, as shown in Figure 21. Laurel wood can be woven in both of these styles as well and is useful in applications that favor high flexibility over structural rigidity. A third style exists where whole or split pieces of bamboo are laid flat and attached parallel to one another with metal wire in the shape of a fence. This type of wicker is highly flexible from strand to strand while inflexible along the length of the strands and can be rolled up for storage, as shown in Figure 22.

Because Mr. Abdullah Idrissi works by himself, he has a limited amount of time and resources. The geodesic-like design of the house that will be entered into the Solar Decathlon has a surface area of 109 m² that must be covered by wicker. The entire house is also slightly curved due to its dome-like structure as shown from Figures 5 and 6 in Section 2.1.2: History of WPI in the Solar Decathlon. The wicker would either be prefabricated to match this curvature or fabricated flat and bent to shape later. Based on the artisan’s ability to craft 8m² of wicker in 5 to 6 hours, he would be able to create the whole wicker envelope in 68 to 82 hours or one and a half to two working weeks. This number is a best-case scenario and does not account for any work done outside our project or issues that might arise, so we estimate a more conservative production time of one to two months to completion.
4.3.2 Shipping Process of the Wicker Envelope

Shipping the wicker envelope will be challenging because of the way it is designed and built. Wicker is composed of many distinct, interwoven parts that depend on each other for structural support, so it cannot be broken down into smaller pieces without compromising the entire structure. With this limitation, large sheets of wicker - especially those with some curvature - will take up significant space on a truck and may need to be shipped in multiple loads. However, one pro of the bamboo fence style of wicker is that it can be rolled up and packed tightly for efficient transportation. Otherwise, it would be beneficial to design the envelope such that it combines many different smaller pieces of wicker that could be shipped more easily. Wicker poses little risk of damage during shipping due to its strong structure, so it will not need to be loaded onto a truck in any special way other than to prevent movement.

4.3.3 Assembly Process of the Exterior Envelope System

The assembly process for the exterior wicker envelope at the construction site will take advantage of the prefabricated wicker pieces to facilitate installation. The wicker is intended to be placed overtop the exterior walls of the house and mounted to a frame after the interior walls are constructed. The exterior envelope provides an aesthetic appearance and environmental protection rather than structural support for the house. To attach the wicker to the house, it is possible to feed ropes or hooks through the openings between the weaves and secure them to mounting points on the walls or frame. If the envelope design called for flat sheets of wicker instead of premade curves, this is the step where curvature would be induced. Curvature can be added by making the mounting points on the wall closer together than they would be on the wicker, forcing the wicker to bend outward to match the shorter length. It may be beneficial to mount the wicker around some guiding bracket (such as a U-shaped piece of metal) to make sure it curves symmetrically and uniformly. When unmounting the wicker from the house during disassembly, the process involves untying the restraints and gently allowing the wicker to return back to its normal shape. The wicker can easily be reused and remounted without any issue with proper restraints.

4.3.4 Ranked Analysis

The five wicker styles for the exterior envelope are whole bamboo weave, bamboo rolls, split bamboo weave, whole laurel wood, and split laurel wood. These options were chosen based on the capabilities of the wicker artisan, Mr. Abdullah Idrissi. Table 7 shows the scores for each of the criteria of the five envelope design options.
Three criteria—materials, weight, and assembly and disassembly—were the most important considerations for the exterior envelope. For the materials, the shape of the house requires the wicker to be curved. The two laurel wood options scored the highest because they allow for the most curvature. Split bamboo is the next best in curvature, while split and whole bamboo allow very little curvature. For weight, the split bamboo weave weighs the least, giving it the highest ranking while the whole laurel wood weighs the most and has the lowest ranking. To assemble and disassemble the constructed pieces, it would take the least amount of time for the wood pieces due to its ability to have more prefabricated curved pieces that could be put into place as opposed to the more rigid bamboo structures.

Several following criteria were weighted as a 2. In terms of maintenance for each of the two materials, the wood would require the least amount of maintenance since bamboo deteriorates faster in comparison, so the wood was scored higher. Due to the artisans’ surroundings, bamboo supply is much higher than the laurel trees. However, either material can be ordered from other supplying wicker sources for construction of the house. Therefore, the sustainability of bamboo was ranked higher than the wood. When creating the wicker pieces for the envelope, the production time is important to consider due to deadlines that would have to be met before the competition date and
because Mr. Abdullah Idrissi works alone. If manpower is a limiting factor, more people can be hired to assist with production. The whole bamboo weave and whole laurel wood would take the least amount of time to construct since there is less cutting, shaving, and weaving of the materials. Thus, the split bamboo weave received the lowest scoring for the highest production time. For shipping, the bamboo roll scored the highest since it is able to be rolled up while the other four options would have to be shipped flat. The last criteria weighted as 2 was aesthetics. Overall, the aesthetics was ranked the highest for the split bamboo weave due to the intricacy of the design as opposed to the bamboo rolls that did not have the woven patterns that could be seen in much of Moroccan wicker crafts.

In the end, the highest weighted scoring option was the split bamboo weave followed by the split laurel wood. The scored options decreased after that from whole laurel wood, whole bamboo weave, and then bamboo rolls.

4.4 Specification Sheets

With production, assembly, and shipping data of zellige, leather, and wicker gathered from interviewing, observing, and shadowing craftsmen, we organized this information in the form of specification sheets to be delivered to members of the Team OCULUS Design Group. These specification sheets for zellige, leather, and wicker detail the important aspects and various options for each craft. Each specification sheet was broken up into four main sections: production details, design details, shipping and assembly, and design options. The zellige and leather specification sheets also had a color options section. These specification sheets will be used by the Team OCULUS Design Group in several different ways. The main purpose is for the Design Group to be able to make an informed decision on the three house features. Some of the information, like the weight and size, will be used for structural calculations and technical model estimations. The specification sheets for zellige, leather, and wicker can be found in Appendices E, F, and G, respectively.

4.5 Results Summary

In this chapter, we provided the results of our interviews, observations, and shadowing of artisans. We gathered details and photos of the production, shipping, and assembly processes for zellige, leather, and wicker and determined how they might be applied to the flooring, insulation, and exterior envelope. This information was organized into specification sheets for the Design Group of Team OCULUS. We then performed a ranked analysis on the different options for the three house features. In the next chapter, we will provide our recommendations from the results of our ranked analysis.
This chapter presents our recommendations and conclusion regarding the project. The following recommendations have been proposed for use in Team OCULUS’ Solar Decathlon house and can be considered for future implementation:

1. **We recommend to use zellige square tiles for the flooring system of the house.**

2. **We recommend to use sheepskin leather for the leather pouf insulation system.**

3. **We recommend to use split laurel tree wood for the exterior envelope system.**

The recommendations were determined by the weighted results of the ranked analysis of the multiple options for each feature. We analyzed the different outcomes from the ranked analysis and justified the best options and viable alternatives for use in the house. Recommendations include which available option is best for each feature, who to commission for the work, when to communicate the designs and begin production, when each feature should be completed by, and when the shipping process should start.

### 5.1 Flooring System Recommendation

We recommend using **square zellige tiles** for the flooring system of the house. We chose this option based on the results of our ranked analysis. From the ranked analysis, we identified square zellige tiles as the best option followed by the zellige wedges. One of the deciding criteria was the weight because zellige tiles are heavy. While the overall weight of the total floor will not change, larger individual pieces will make the flooring more difficult to handle and install. Smaller, square tiles will be easy and light enough for one person to handle. Other criteria that were important to the flooring were assembly/disassembly, aesthetics, and sustainability. Sustainability is important as it is one of the main themes of the Solar Decathlon. Traditional zellige can be unsustainable and cause pollution due to the wood-fired kilns used. However, Moresque has made an effort to become more sustainable by using biomass for their ovens and moving tile production outside of Fes.

Zellige wedges are another viable option for the flooring. Each individual piece may not be as light as the square tiles, but the weight would still be manageable. The assembly would be easier than the square tiles because there would only be 12 pieces to assemble as opposed to a large number of smaller square tiles. With square zellige tiles identified as the best option, we made a plan and timeline for the construction and installation of the flooring system.
**Moresque** will be the source for the zellige tile work. The zellige flooring construction for the solar house is estimated to take one month. With the competition in September and the trial build of the house scheduled for late July, the **initial design phase** for the flooring should start in early March and no later than the end of March. Team OCULUS leaders and Moresque need to set up meetings to start discussing design options. In order to shorten the production process, most of the floor can consist of simple tiling made with larger square zellige tiles. An accented feature in the center of the floor or smaller designs around the edges can be added to integrate more complex zellige tiles. Once the design is finalized, Moresque can begin making the tiles and assembling the final result. If this process is started during March, **construction** can begin by the middle of April. This would give Moresque a buffer period of one month just in case something slows down construction. The square tiles could then be stacked and shipped to the competition site by truck. A Moresque worker should be hired to assist in the final assembly. Specific dates for the design, construction, and shipping of the flooring system can be found in Figure 23.

![Gantt Chart for the Flooring System](image)

**Figure 23: Gantt Chart for the Flooring System**

### 5.2 Insulation System Recommendation

We recommend using **sheepskin** for the leather pouf insulation system. It was determined as the best option to use for the leather poufs based upon results from the ranked analysis. Instead of using sheepskin, a viable alternative would be to use goatskin since it shares similar qualities with sheepskin. An important deciding factor during the ranked analysis that lifted sheepskin over goatskin was the overall weight.

Poufs made from sheepskin are lighter than those made from goatskin. Since the geodesic-like house will have the poufs integrated into the walls, lighter poufs will reduce the amount of dead weight supported by the walls. Other than the weight criteria, sheepskin and goatskin leather are similar in the aesthetics and sustainability criteria. The final determination of which type of skin will have to be decided by leaders of the structural and design teams of Team OCULUS.

Moving forward, we propose the best location to source the poufs from is the **Craftsman’s House** located in Rabat. They have the ability to produce up to 40 poufs in a week which means they would be able to create the number of poufs necessary for...
the design quickly. Team OCULUS should contact the craftsmen to begin the **initial design phase** for the poufs and to talk about how the poufs will be attached to the support structure. We recommend that they contact the craftsmen no later than the middle of March to start the design and integration process. **Production** of the poufs should start no later than mid-April, and all poufs needed for the insulation system should be completed by no later than the end of June. We recommend the search for a shipping company should start by the beginning of June. Starting the search in June allows for the team to work out final details with the company, including the shipping timeline, when they will arrive at ENSAM, and the cost for shipping. Specific dates for when each step should start and be completed by are listed in Figure 24.

![Figure 24: Gantt Chart for the Insulation System](image)

### 5.3 Exterior Envelope Recommendation

We recommend using a wicker weave of **split laurel tree wood** to construct the exterior envelope. The ranked analysis was the main tool used to determine this recommendation. A possible alternative style to the split laurel tree wood would be the split bamboo weave. Our decision was influenced by the assembly and disassembly process for the different wicker styles. The split laurel wood was the better option since it is easier to construct and install on the house than the split bamboo weaves.

The sustainability criteria were also important to evaluate because it is one of the main themes of the Solar Decathlon, but this was no issue because both the wood and bamboo are sourced locally in Morocco and regrow quickly after they are harvested. Additionally, the appearance of the wicker was something to be mindful of because the envelope encompasses the entire exterior of the house, meaning that any observer would generate their first impression based on what they see.

We propose that **Mr. Abdullah Idrissi** in Skhirat should be the source for the wicker envelope. He will be available to start the **initial design phase** beginning in March. His **production** timeline for completing projects typically spans a month from the start date. Extra production time was factored into the Gantt to account for delays in production. By default, the product will come as flat sheets of wicker that must be bent to achieve a certain curvature, but there is an opportunity to have the artisan prototype other shapes and styles beforehand if the design calls for it. The entire envelope should
be completed by no later than the middle of June in order to construct it in time at ENSAM. We recommend that Team OCULUS start looking at shipping options by the beginning of June to ensure that appropriate shipping options are available. Specific dates for when each step should start and be completed by are in Figure 25.

*Figure 25: Gantt Chart for the Exterior Envelope System*
Team OCULUS has the goal of incorporating African and Moroccan artisanal crafts into the design of their Solar Decathlon entry. Our IQP researched three artisanal crafts that can be used for some of the features of the geodesic-like solar house: zellige tiling for the floor, leather poufs for the insulation, and wicker for the exterior envelope systems. We met with several expert artisans and learned about the history, design practices, and production processes for these crafts. After analyzing our findings, we developed recommendations on the different styles of crafts that should be used for the three house features. For the flooring system, we recommended contacting Moresque to further develop a design for a square zellige tile flooring. For the insulation system, we recommended contacting leather craftsmen in Rabat to use leather poufs made from sheepskin. For the exterior envelope system, we recommended contacting a local wicker artisanal from Skhirat to use a wicker weave of split laurel tree wood. We included specification sheets that contained all of the information we gathered on zellige, leather, and wicker, which were provided to Team OCULUS.

Moving forward, we recommended that Team OCULUS design leaders contact the craftsmen and artisans by the end of March 2019 to start discussing about design options to decide on what the final product will be. Production of the crafts can begin between the months of April and May 2019 and should be completed by the end of June 2019. To further help Team OCULUS, we provided them with a Gantt chart that includes specific windows of time to collaborate and design, construct, and ship the crafts to ENSAM and the competition site in Benguerir. The three specification sheets we created and the Gantt chart will serve as informative and visual aids for Team OCULUS as the Solar Decathlon Africa competition start date approaches.


Appendix A: Interview at Moresque

A. What do the various colors and designs represent?
   Designs are symmetrical, number of pieces varies by size of piece, a larger
design has 100 while the same smaller design has 50.

B. How long will the floor take to construct?
   Depends on the design. Some patterns take 1 week while more complicated
designs will take 3 months. Average time is 1 month.

C. Are we able to combine multiple materials (marble, tilework, zellige
tiling, wood) throughout the floor? Note: Wood is the most movable for
certain modular areas.
   They have combined multiple types of tile and marble together, but they don’t
do hardwood floor. They do use cedar for ceilings, but cedar is not a good wood
for flooring.

D. Are we able to construct certain parts of the floor plan with pre-
fabricated carved holes to put pipes through? Can we create
removable tile covers to go over the holes?
   Yes, it’s like with marble. Put a pipe through a carved hole and cement it shut.

E. What are some price estimates for the certain styles, materials, and
designs?
   Designs with smaller pieces (i.e. more intricate designs) are more expensive.

F. What is the weight of each proposed wedge? If it has a 10 cm
   thickness, how much would the wedges weigh?
   One square meter of tile weighs 17kg before installation and 20 kg with
   glue.

G. Is there a certain design that would work better with the shape of the
   wedges? A design in the center under the skylight? Or designs around
   the edges?
   Lots of 10cm square tiles are usually used for floors, bathroom-like tiles are
   sometimes used for floors or walls. Octagons consisting of 5cm squares also
   used for floors.

H. Should we ship this is certain sized wedges? Or should they be smaller
to be easier to ship?
   They make lightweight, interlocking square tiles that are shipped to the US by
   plane. However, they don’t see an issue with shipping wedges of this size with a
   truck.

I. Which material will be the most durable and most fragile to ship?
   Zellige is strong enough to survive shipping from Morocco to US by plane, so
   shipping by ground should not be an issue. Care should still be taken with
   transport.
J. For the final product, will it be easy enough for students to put wedges together or will there need to be zellige workers there to glue it together in a specific way?
   A trained tile worker would have to be present to do the final installation.

K. Is there a specific coating on the zellige tiles that will need time to set/dry? Or will that be pre-fabricated and only need to be laid down and glued together at the build site?
   A cement binding agent is used to join tiles together.

L. Can the wedges be put together and taken apart multiple times or can they only be set once?
   No, they can be placed only once.
Appendix B: Interview with Rabat Leather Artisans

A. What materials are there to choose from?
Rabat artisans use sheep for seat cushions.

B. What are the different characteristics of each type of leather?
Goat and sheep are softer and more pliable. Cow and camel are rougher to the touch and are less flexible.

C. Where do you source the materials?
Leather is sourced from Fes tanneries and assembled in Rabat.

D. Do different designs or colors affect the cost?
Yes, more complex designs (i.e. more intricate stitching) cost more.

E. Can the bags be made into shapes other than circles? Note: We are thinking of making triangles
Any shape is possible.

F. Will different shaped poufs be more expensive than the normal circular or saddle shape?
Shape doesn’t really affect cost unless it takes a lot longer or a lot more material to make. Embroidery takes more time and costs more.

G. What is the limit to how large you can make the poufs?
Multiple sheets of leather can be sewn together if something bigger is needed.

H. What can you stuff the poufs with? Are there certain materials you can put inside the poufs to provide insulation?
Poufs are stuffed with fabric made from recycled blankets.

I. How durable is leather to certain elements like rain, temperature, and sun radiation? Are there different coatings to help protect leather?
Poufs don’t hold up to rain well and no coatings are applied to help this.

J. Is there a certain treatment to remove the smell associated with leather?
There are two types of leather one that smells and one that does not. Leather that doesn’t smell is more expensive because more time and water is put into cleaning it.

K. How heavy is each pouf?
Average bag weighs 1kg for just the leather and 5-7kg if stuffed with fabric.

L. How long does it take to produce a small leather pouf? How long would it take for a larger one?
Can produce 40 leather poufs in a week.

M. Once sealed, is there any risk of them accidentally opening up again?
They use a zipper to seal in the material so it can be opened and closed again.

N. Is there any maintenance that must be done to make sure the leather stays in good condition?
Leather should not need to be maintained.
Appendix C: Interview with Mr. Abdullah Idrissi

A. What materials do you typically use for wicker?
   Materials are sourced from whatever grows nearby. So that means just bamboo
   and wood from a laurel shrub

B. Are there any plastic or synthetic materials that can be used instead?
   Only natural materials are used

C. Will these materials deteriorate in the rain or sun?
   Green bamboo will dry out over the course of two weeks and turn yellow

D. Are there any special treatment(s) to make these materials fireproof
   or otherwise increase durability?
   Coatings can be applied but aren’t typically used

E. Can this be woven in such a way that water cannot pass through?
   Small strip weaves can be made really tight but will still have some small holes

F. How large can you make one continuous wicker structure?
   Usually only as large as a stalk of bamboo but multiple pieces can be tied end-to-end

G. How long does it take to make wicker?
   Depends on intricacy, 8m² would take 5-6 hours to complete

H. How do you weave bamboo into rolls instead of in sheets?
   If you want it to be rolled, you can't weave it. It has to be made in single
   bamboo strips tied together with wire

I. Can wicker be curved or bent?
   Can be curved with a lot of force. The higher the curvature, the thinner the
   strands have to be. Laurel wood is a lot more flexible than bamboo and creates
   sharper curves

J. How much does the wicker weigh?
   Density of bamboo is about 0.5g/cm³, laurel wood is 0.8g/cm³
## Appendix D: Specification Sheet for Zellige Tiles

The following document provides specifications regarding the production, design, and shipping and assembly details regarding zellige tiles for the flooring system.

### Production Details

**Production can take anywhere from 1 week to 3 months.**
- A. Simple designs with larger tiles and less pieces will take about 1 week.
- B. More complex designs with smaller tiles and more pieces will take about 3 months.
- C. Most designs will take an average of 1 month.

**Holes for piping can be drilled into the flooring.**
- A. Typically, holes will be drilled and a pipe will be fitted and cemented into place.
- B. Another option to allow for pipe positions is to drill a hole with a tile piece that would fit over top.

**Modular tiles can be made to make transportation and installation easier.**

1 m² of tiling with glue is 20 kg (44.1 pounds).

### Design Details

**All zellige designs are symmetrical and colors are complementary.**
- A. New colors can be created upon requests from clients.

**Multiple types of materials can be used in one design.**
- A. Zellige tiles are most commonly used.
- B. Marble and other types of tiles can be used with zellige tiles.
- C. Moresque does not specialize in hardwood floors.

**Floor can be made in different shapes such as wedges or square tiles.**

**Tiles come in several different shapes.**
- A. Sizes: 10 x 10 cm squares, 5 x 5 cm squares.
- B. Shapes: hexagons, octagons, diamonds, rectangles, squares.

**Figures D1 & D2 show the available color options.**

**Figures D3 – D15 show different design and pattern options available.**

### Shipping and Assembly

They can make lightweight tiles that are strong enough to be shipping by plane.

Wedge shaped pieces of flooring will be able to be shipped by truck.
Assembly cannot be done by just the students, at least one craftsmen would have to be hired to help with assembly at project site.

<table>
<thead>
<tr>
<th>Wedges should only be put together once.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. The wedges will only be able to be placed once at the final project site in Benguerir.</td>
</tr>
<tr>
<td>B. Moving them multiple times will increase the risk of breaking the tiles.</td>
</tr>
<tr>
<td>C. Wedges are glued and cemented together once assembled.</td>
</tr>
</tbody>
</table>

Color Options

![Color Options](image)

*Figure D1: Different Color Options Available for Zellige Tiles*
Design and Pattern Options

Figure D2: More Color Options Available for Zellige Tiles

Figure D3: Lightweight Modular Interlocking Zellige Floor Tile Sample

Figure D4: Zellige Floor Sample with Marble Accented Edge
Figure D5: Simple and Complex Design Zellige Floor Sample

Figure D6: Another Simple and Complex Design Zellige Floor Sample

Figure D7: Zellige Floor Sample: Diamonds with a Wavy Edge

Figure D8: Zellige Floor Sample: Octagons with Diamond Center Pieces

Figure D9: Zellige Floor Sample: Square Checkered Pattern
Figure D10: Zellige Floor Sample: Interlocking Apple Core
Figure D11: Zellige Floor Sample: Two Rectangles to Make a Square
Figure D12: Zellige Floor Sample: Small Hexagons

Figure D13: Zellige Floor Sample: Star and Diamond Pattern
Figure D14: Zellige Floor Sample: Large and Small Angled Squares
Figure D15: Zellige Floor Samples: Large and Small Squares, Diamonds, and Trapezoids
The following document provides specifications regarding the production, design, and shipping and assembly details regarding leather poufs for the insulation system.

### Production Details

<table>
<thead>
<tr>
<th>There is the ability to produce up to 40 leather poufs a week.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Does not vary with different shapes as long as they are relatively the same size.</td>
</tr>
<tr>
<td>B. Can request triangular shaped poufs to be produced.</td>
</tr>
<tr>
<td>C. Embroidery adds to production time.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sheep skins are typically used.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Goat skin can be an alternative, but is softer to touch and is more expensive and pliable.</td>
</tr>
<tr>
<td>B. Cow skin can be an alternative, but is rougher to touch, is less expensive, and is more rigid.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>It is sourced from the tanneries in Fes and assembled in Rabat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Two separate types of leather.</td>
</tr>
<tr>
<td>B. One type has an odor but costs less.</td>
</tr>
<tr>
<td>a. Second type has no odor but costs more.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>It does not hold up to rain.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Oil can be applied to give water protection.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>An empty leather pouf weighs about 0.907 kg (2 pounds).</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Maximum weight is between 4.53 – 6.80 kg (10 – 15 pounds) and depends on what is inside the pouf.</td>
</tr>
<tr>
<td>B. To open or close the pouf for filling purposes, a zipper is sewed on to the back side.</td>
</tr>
</tbody>
</table>

### Design Details

<table>
<thead>
<tr>
<th>Colors do not affect the cost.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Easy to get any color from the tannery.</td>
</tr>
<tr>
<td>B. Tanneries already use all natural color dyes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complex designs with intricate stitching increases the cost.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>There is an ability to press and stamp different designs on to multiple sheets of leather.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Can provide our own stamps or use ones already in circulation.</td>
</tr>
</tbody>
</table>

| If a lot of material is used, the cost may increase. |

<table>
<thead>
<tr>
<th>Figures E1 – E6 show different design and pattern options available.</th>
</tr>
</thead>
</table>

| Figure E7 shows all possible color options for the poufs. |
Shipping and Assembly

Empty leather poufs can fold in on themselves, providing an easy way to transport many of them at once.

**They can easily be attached and detached from the walls.**

A. Weight may be an issue depending on the type of leather and insulation used.

Design and Pattern Options

*Figure E1: Small Leather Saddle Pouf Made from a Single Sheet of Leather*

*Figure E2: Larger Leather Saddle Pouf Made from Multiple Sheets of Leather*
Figure E3: Circular Leather Pouf Top with Printed Designs and Embroidered Edges

Figure E4: Different Types of Stamps that can be Pressed on to Sheets of Leather
Figure E5: Large Stamp used for Center Press of Saddle Pouf

Figure E6: Large Stamp used for Edge Press of Saddle Pouf

Color Options

Figure E7: Multiple Color Options Available for Leather Poufs
The following document provides specifications regarding the production, design, and shipping and assembly details regarding leather poufs for the insulation system.

### Production Details

**Bamboo and laurel flower branch are two materials that are commonly used to weave.**
- A. Bamboo is more rigid.
- B. Laurel flower branch is more pliable and flexible.
- C. Mr. Abdullah uses any material that is around him in terms of plants (bamboo, laurel flower branch, etc.)

**Specific tools are required in the production of wicker designs.**
- A. Flat plane.
- B. Saw.
- C. Knife.

**Bamboo and laurel flower branch have similar production processes.**
- A. Bamboo
  - a. Bamboo branch is cut and then the outer shell is taken off.
  - b. A flat plane is used to shave the rest of the bark off.
  - c. A knife is used to cut the bamboo into half and is further shaven down.
  - d. Bamboo is cut in half again, and then fully shaven down to just the bare bamboo.
  - e. Bamboo strips are then woven.
- B. Laurel flower branch
  - a. Branch is initially cut from the bush.
  - b. A flat plane is used to shave the bark off to get green/white wood underneath.
  - c. Sandpaper is used to make it smooth.
  - d. Sometimes, it will be further cut into halves or thirds to make it more flexible. If cut in half, Mr. Abdullah uses a machine to remove the core of the wood.

**Bamboo requires a lot of water so it is grown near rivers or other water sources.**

**There is a difference between green/fresh bamboo and brown/dried bamboo.**
- A. Green bamboo is heavier because there is still liquid trapped inside.
- B. Brown bamboo is lighter because their water weight has evaporated. It takes about 2 weeks for the bamboo to dry up in the sun.

**The production time depends on the intricacy of the design.**
A. 4m x 2m wicker sheet would take approximately 5 – 6 hours.

**Design Details**

Different products can be made from certain materials. There sometimes are more optimal materials for certain products.

A. Shelves, furniture, bungalows, chicken coops, and fences are usually made from bamboo due to rigidity.
B. Rocking chairs and lounge chairs are usually made from the laurel flower branch due to the flexibility.

The higher the desired curvature of the wicker, the thinner the strand has to be. Smaller strips of the laurel flower branch has more curvature and can also undergo reverse curvature.

The wicker can be woven less tightly to allow for more light to pass through.

If you want it to be rolled, you cannot weave it. You have to make it in single bamboo strips that are tied together with wire.

You can drill holes into the bamboo.

A. You can push other bamboo pieces into it to create a connected structure.
B. There are different sized tools to create different sized holes.

Bamboo can be painted once it has dried.

Figures F1 – F11 show different design options for the wicker

Figures F12 – F15 show the different weights associated with bamboo and laurel wood

**Shipping and Assembly**

They can be shipped by truck in wedges that can fold in on itself.

A. Wedges can be created so that it can be shipping more compactly.

Wedge pieces can be placed and strung together by a strong wire or some type of metal joint on the exterior envelope.
Design Options

Figure F1: Green and Fresh Stalks of Bamboo

Figure F2: Brown and Dry Stalks of Bamboo

Figure F3: Hollowed Out Bamboo (left) and Wood Branches (right)

Figure F4: Non-hollowed Out Bamboo (left) and Wood Branches (right)
Figure F5: A 2.5 m X 8 m Chicken Coop Wall

Figure F6: Rolled up Sheet of Bamboo Held Together with Wires

Figure F7: A Sheet of Wicker Undergoing the Maximum Possible Curvature

Figure F8: A Bamboo Structure of a Connected Corner
Different Weights for Each Type

Figure F9: Maximum Curvature of the Laurel Flower Branch

Figure F10: Reverse Curvature of the Laurel Flower Branch

Figure F11: Thin Branch Providing the Maximum Amount of Curvature

Figure F12: Weight of a Single Laurel Flower Branch

Figure F13: Weight of Four Dry Bamboo Stalks

Figure F14: Weight of Five Partially Dry Bamboo Stalks

Figure F15: Weight of Five Green Bamboo Stalks