Architecture in the Age of Semi-Autonomous Machines

An Honors Thesis (ARCH 402)

by

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Muncie, Indiana

May 2012

Expected Date of Graduation

May 2012
Abstract

Armed with complex motion controls, sophisticated sensors, gyroscopes, and fast computers, a new generation of semi-autonomous machines has evolved with high levels of spatial awareness, memory, and animal-like dexterity. These systems possess astonishing powers—including the ability to navigate elevated terrain, avoid obstacles, and react to constantly changing environmental circumstances in real time. Applying these new technologies to architecture is the main goal of my Honors thesis. My project is a design proposal for a new type of off-road, mobile housing system that could be utilized as an alternative for the current social practices of Senior Full-time Recreational Vehicle Communities in the South Western United States. This clientele consists of a large demographic of retirees who have relinquished their sedentary homes for a life off-the-grid and on the road. These Internet connected, modern day nomads are estimated to number between two and three million. Ultimately, I will be designing a multi-functional, self-contained, satellite up linked, web connected, solar powered, walking house that—unlike an automobile or RV—does not require customized environments—such as roads—to function smoothly. The result is a noninvasive ‘post-infrastructure’ urbanism that results in the development of nomadic cities while still leaving the natural world unconstructed, untouched, and unharmed.
Acknowledgements

I would like to thank my studio professor Mike Silver for advising me through this semester-long project. This project would not exist had it not been for his ambitious prompt and expectations. Furthermore, it was his insistence on learning and implementing new state-of-the-art tools that defined the very nature of this project.

I would also like to thank all of my studio classmates who assisted in the completion of this project, including: Lauren Diaz, Robert Gordon, Justin Gross, Taylor Metcalf, and Lovelyn Pastrana.

Lastly, special thanks to the College of Architecture and Planning at Ball State University for not only providing my classmates and me with an outstanding education, but providing us with the necessary tools and technologies to complete this project.
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The following pages document the design process of this off-road, mobile housing prototype completed for my ARCH 402 course. It is an explanation of both what we did and the implications it has on the field of architecture—which are many. Ultimately, all of these advancements in robotic locomotion are resulting in the development of a mobile architecture that will leave the world unconstructed. By utilizing these ‘post-infrastructure’ robots, highways and sidewalks will theoretically vanish. Through the use of legs instead of wheels, these machines would be able to move large, inhabitable spaces across difficult terrain. Potential pathways through the wilderness are limited only by the length of a stride, the tread of a foot, and the torque of a motor. In the end, these mobile buildings encourage a sustainable, non-invasive urbanism that could potentially solve the discordant agendas of both the developer and the preservationist.
In order to better understand the limitations and capabilities of robotic technologies, the design process began by examining the parts and assembly of a Trossen Robotics Quadruped Kit (pictured below).

After assembling the entire kit in order to better understand the robot's parts and construction, it was then disassembled for documentation purposes. My classmates and I began dimensioning every piece of the robot with calipers in order to create an exact digital replica of the model.
This allowed us to begin designing our own parts on the computer in order to completely retrofit and customize the entire kit. As a result, we were then able to begin designing a functional robot that could also meet our programmatic needs of habitation.
Schematic Design

The next step in the design process involved each student coming up with an individual solution for the project. In order to find some design precedents, I began by looking up the concept art of fully autonomous robots from motion pictures—including Pixar’s *The Incredibles* (see below).

I then used these precedents to help establish my own preliminary design for the Trossen Robotics kit.
My research and ideas included a few, easily applicable solutions that could work with a multitude of designs. I also completed a series of technical drawings in order to better convey my design and these solutions. For instance, one of my initial proposals was for a square plan in which the legs were to be positioned at the corners of the frame in order to increase the robot's range of mobility.

I also proposed the possibility of using the roof for both water collection and storage while traveling.

Lastly, I introduced the idea of having a habitable space below the main chassis and discovered that the robot could still climb slopes up to 20 degrees if the body was rounded.
After seeing all of the individual work, my studio professor divided us into teams of six and told each team to implement all of our ideas into one final robot design—using both existing pieces from the kit and new customized pieces. Furthermore, the design of the robot had to resemble a basic three-dimensional shape (such as a cube). Therefore, when at rest, the robot would look like something very simple and mundane; but upon "opening-up" to walk, it would transform into something entirely new and unfamiliar to the viewer.

We then began designing new pieces and parts and cutting them out of 1/8" thick sheets of acrylic with a laser cutter. Next we assembled a model with all of these new parts. By creating larger pieces for the legs, we were able to have the robot come close to folding-up entirely into a box.
However, we soon found that the assembly of these parts was very difficult and imprecise. Also, we failed to come up with a design that resulted in a completely monolithic cube. Most importantly, we realized that the laser cutter was constricting us to design two-dimensionally. Therefore, my team began learning how to operate CNC milling machinery in order to design and produce parts and pieces that were three-dimensional. This process of manufacturing three-dimensional components is very similar to the prototyping found in the automobile industry.

In just a few weeks, we came up with a new preliminary design utilizing the three-dimensional capability of the CNC mill and began milling these prototypes for the robotics kit. These parts required complex experimentation with tool path writing and flip operations on the CNC machining bed. Our first prototype was done using laminated sheets of Medium Density Fibreboard (MDF).
Overall, this simple MDF prototype was much more successful than our previous model. It utilized and developed a variety of ideas from my initial schematic design proposal. One of which was the square plan in which the legs are positioned at the corners of the frame in order maximize space efficiency and minimize their impact on the floor plan. By connecting the robot's servomechanisms (the leg motors) to the middle of our customized leg pieces instead of the top, the extended leg pieces are able to enclose all four corners of the robot from top to bottom. Also, because the middle of the legs must taper inward to snugly hold the servomechanisms, the body of the robot was also designed to taper inward in order to reflect this move and establish uniformity. Ultimately, the placement of the servomechanisms allowed the leg to fold "up" instead of "under"—resulting in one monolithic shape when folded-up at rest. Based on the success of this prototype, we decided upon continuing with this general shape and design and spending the remainder of the semester refining it.
Despite the overall success of our first MDF prototype on the CNC mill, there were a few issues we had to address in our next prototype. First of all, the additional weight of our new customized pieces was too much for the robot's motors to handle. Although it could open-up, it could not easily walk. Therefore, the thicknesses of all of the pieces had to be greatly reduced. However, because MDF is extremely brittle, we could not significantly reduce the material thickness without jeopardizing its structural integrity. Therefore, the second prototype was made using 6 lb. foam. This material was not only lighter, but also stronger—allowing us to achieve extremely minimal tolerances with each of the pieces.
Because of the incredible precision with tolerances, we were also able to fix a few other issues regarding the formal aesthetics of the robot. For instance, the thinner pieces allowed for a much sleeker and sharper manufactured look. They also helped minimize all the joint connections and made the entire robot look more unified and monolithic. Also, the tapering that occurs where the servomechanisms connect to the legs was further enhanced with a more pronounced response from the body of the robot. This inward taper became a prime location for windows that responded to the formal gestures of the robot. Lastly, the top piece of the robot was redeveloped in order to be utilized for water collection. Because these mobile houses are to be used in southwest, water collection and storage while traveling is a very critical issue. Utilizing the roof for this purpose was also one of my original ideas during the schematic design process.

After the foam prototype, we had decided upon our final form and were ready to produce our final model. However, the foam prototype led us to make a few changes. Although the individual tolerances of the pieces seemed acceptable, the foam itself was not very sturdy when it came to walking and supporting the weight of the robot's motors. Furthermore, the overall quality of foam—both aesthetically and functionally—was not as high as we desired. Therefore, we saved up to purchase a material that would be more visually pleasing, as well as stronger and more functional. After much searching, we ended up using 48 lb. NC Proof Board.
The following pages contain the final results of the semester-long process
Process Summary

Started with a basic cube.

The roof was indented to allow for water collection.

The legs were tapered inward to hold the servos.

The walls also followed this gesture in order to keep the form uniform and cohesive. These indentations became strategic locations for windows.
assembly diagram of customized components
assembly diagram of entire kit
(both customized and original components)
The lower portion of the robot is a plenum space for all of the mechanical equipment, motors, servomechanisms, and operating systems. It is also where the entry occurs—via a staircase on the inside of one of the legs.

At the top of this staircase is the first level. We developed a simple open plan that allows users to apply a variety of different floor plans depending on their needs. Typically, this floor would be the main level and contain the living room, kitchen, and bathroom.

The second level would primarily consist of a bedroom loft. It would also have roof access and storage space.
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