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"Zome": An Interactive Art Piece

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‘Zome’: An Interactive Art Piece

An Honors Program Project Presented to

the Faculty of the Undergraduate

College of Integrated Science and Engineering

James Madison University

in Partial Fulfillment of the Requirements

for the Degree of Bachelor of Science

by Dylan Chance, Cassidy Moellers, and

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Abstract

As our communities expand rapidly, both physically and digitally, we can lose our sense of connection and togetherness. Interactive and participatory art interventions cultivate community by provoking engagement in unexpected areas. In this project, the prototype for an interactive zonohedral dome (or “zome”) was constructed as a proof of concept for an art intervention to engage students in collaborative STEM (Science, Technology, Engineering, and Math) learning, by creating feelings of connection with the technology and with each other. Consequently, it demonstrates the values of the STEAM (Science, Technology, Engineering, Art, and Math) movement in education. Design elements (and an assessment approach) were selected based on a comprehensive literature review, which focused on the aspects of engagement that would boost participants’ interest in and proficiency with STEM subjects.

A zome is a structure that supports itself solely due to its geometry. No nails or glue are used in the construction. The interactive nature of the structure emerges from sensors that detect occupancy, with music and lights automatically responding to the pattern of people entering and leaving the zome. Many technologies were combined to create this experience, such as SketchUp (to design the components), Makerbot Replicator II (to build the structure), Arduino (to detect occupancy via phototransistors), LightShowPi (to generate Fast Fourier transforms of music files and control the frequency and amplitude of audio communicated via LEDs), and RaspberryPi (a microcomputer to run LightShowPi and translate the signals from the Arduino to play audio at pre-designated decibel levels).
Chapter 1: Introduction and Background

Students who are otherwise not inspired by Science, Technology, Engineering and Math (STEM) can be drawn to the potential and practical application of these subjects to create art and music. As a result, the goals of this STEAM (Science, Technology, Engineering, Art, and Math) project are to 1) prototype a geometric structure called a *zonoherdal dome* (or zome) to serve as a platform for an interactive (and ultimately, participatory) art installation, and 2) articulate an assessment approach that can be used to evaluate and track patterns of student engagement. The presence of observers, and their interaction with the zome structure itself, controls programmed sound and light shows that respond to the movements of the participants. The design elements were selected because of reviewing a cross section of the academic literature in art and art criticism, training and performance improvement, education, learning, and psychology.

The idea for interactive art that engages participants in science and technology, enhancing literacy through sound and light shows, is not new. For example, chemist David Glowacki has created *danceroom Spectroscopy*, an "interactive chemistry video game" playing a dual role as performance art, which lets players see their energy fields and use it to control the motion of atoms and molecules. A fully participatory art piece, the installation not only responds dynamically to the presence of the participants, but also allows them to engage with the material directly, purposefully modifying the art in the process of experiencing it. (Glowacki, 2014) However, extending this style of approach to create a pedagogical platform for engagement is new, and is the primary contribution of this project.
Although the prototype for the zome is only half a meter in diameter, the full-scale ("mature") model will be large enough to comfortably support up to 30 occupants. In both its prototype and built-out forms, the zome will engage participants with an audio and visual experience. This design reflects the innovative work of other artists. By directly engaging the participants with the art through the interaction, the zome can promote collaborative STEM (Science, Technology, Engineering, and Math) learning by showing participants how to create an immersive sensory experience using electronics, algorithms, and a minimal amount of programming.

1.1 STEM to STEAM: Facilitating Literacy, Innovation, and Collaboration

Recently, the acronym STEAM (Science, Technology, Engineering, Art, and Math) has emerged in the literature on education to reflect a growing need to extend an awareness of art and the practices of art into a scientific understanding and appreciation of the world. (Hall, 2013) Furthermore, proactively creating connections between science and art has been demonstrated as an approach for sensitizing people to their connections with nature and sustainability. (Clarke & Button, 2011) Because coursework in the arts is inquiry-based, driven by asking questions rather than solving expressly stated problems, the skills associated with creativity and innovation are stimulated naturally by engagement with artistic pursuits. The zome, as a STEAM project, will help raise participants' awareness of the connectedness of art, science, and technology, while engaging them in the opportunity to create even more art by manipulating electronics through programming.

1.2 Participatory Art vs. Interactive Art: Creating Meaning through Narrative

Interactive art has been explored as a subject of research because the medium of interactivity can promote the discovery and development of meaning. (Muller and Edmonds, 2006) The artist,
audience, and artifacts are positioned as essential elements of a dynamic and evolving system where “meaning occurs through the process of exchange, and interactivity itself is the very medium of the work.” That is, a participant can learn more about him or herself by reflecting on an experience with art, particularly when that experience requires action on behalf of the observer.

Whereas interactive art provides a means for its creator to engage with his or her audience in the construction of a story, participatory art, in contrast, plays the role of narrative. By leaving the nature of the participation more open-ended than in interactive designs, the creator acknowledges that the participant is actively engaged in discovering and developing meaning by reflecting on their own ability to transform the art itself. Participatory art, like interactive art, “influences us and affects our perception of, and our actions in, the world” (Novitz 2001).

Including the audience in the process of making meaning, through an iterative process of creating and displaying the audio and visual components of the zome, shifts the emphasis from consumption to fostering a culture of participation and contribution. The initial version of the interactive zome is not intended to be participatory, which would enhance the practices of self-reflection and making meaning. However, the concept of the zome as responsive to the movements and interactions of participants can easily be extended into participatory art, as opportunities are identified for participants to program the sound and light shows as part of the experience of the art, even contributing their own unique tracks to the zome's library of selections. The zome, then, provides a platform to transition from the interactive to the participatory paradigm.
1.3 The Zome as a Participatory Art Intervention

In its maturity, the zome is envisioned as a fully participatory piece that changes and morphs in response to the contributions made by participants and observers. These contributions can be directed towards individual and group performance enhancements. Performance improvement interventions are often applied in human resources situations to close an identified performance gap (Performance Improvement, 2005). Although training programs are one of the most commonly implemented performance interventions, determining an appropriate intervention for a particular gap requires examining environmental, organizational, cultural, emotional, and political factors. Performance interventions share some characteristics with participatory art installations, in particular, that they both require people to *do* something for them to "work". (Simon, 2010)

Works that are characterized as *art intervention* are not typically included in mainstream exhibition areas such as museums, shows, and galleries (Letsiou, 2012). Letsiou characterizes art intervention as being defined through social exchanges and transformations on behavior, social collaboration, and creating new intellectual potential. Masemann (2014) elaborates on this definition, establishing that art interventions “may be characterized as spontaneous, provocative, eccentric and often humorous or absurd. They comprise a series of spatial, relational and participatory art practices whose underlying synergy resonates with the contingent, unstructured and variable qualities of molecular exchange. On the surface they appear sporadically and unexpectedly, momentarily disrupting usual associations made between people and phenomena.” As a result, art interventionists seek to help those engaged in participatory art discover and develop meaning specifically by illuminating outmoded assumptions and responses.
The zome can be characterized as an art intervention to close the interest gap for students who otherwise would not make the connections between science and technology skills and producing art. Initially, it will be an interactive art intervention because although the displays will respond to participants' presence, there will not be an opportunity for participants to actively engage in modifying and renewing the piece. At maturity, it will serve as a participatory art intervention because it will be installed external to a traditional place of art, and it will be used to stimulate the interactions and discussions between people that disrupt prior patterns of action and thought. Furthermore, such an art intervention is positioned to influence the individual’s education process, because it can surprise the participant by showing them how science and technology can be leveraged for experience design. This is also discussed by Letsiou (2012) who states that: “...art intervention precipitates [sic] the educational event and places the artist/student in the role of a producer of learning conditions [sic] rather than in the role of an authority of meaning. In parallel, the teacher who adopts art intervention as a teaching method questions his role as the sole possessor of power and knowledge in the classroom, a fact that reminds us of Freire's approach of ‘teacher-student and student-teacher’ (Freire, 1972). Furthermore, a curriculum that includes art intervention focuses on the creative process rather than on the final product. Therefore, the students who assume the role of artists learn that when power and authority are transformed into coordinating structures, they can constitute a cause for exploring knowledge and the nature of relationships.”

Through the mechanism of the participatory zome, community members will be thrust into a creative process where all participants (at any intellectual level or stage in discovering and
creating meaning) can contribute to the interpretation of the structure, developing meaningful relationships as part of the practice.

1.4 Situated Learning in the Zome

Situated learning is an instructional approach developed by cognitive anthropologists Jean Lave and Etienne Wenger in the early 1990s, who developed the community of practice concept. It follows the work of Dewey, Vygotsky, and others who claim that students are more inclined to learn by active participation in the learning experience through a process of inquiry. Instead, Lave’s situated learning theory supports the idea of active learning, where learning is facilitated instead of delivered by teachers to students.

John Seely Brown’s concept of “learning-to-be” is also partially grounded in situated learning theory. Brown explains, “today’s students want to create and learn at the same time. They want to pull content into use immediately. They want it situated and actionable—all aspects of learning-to-be, which is also an identity-forming activity. This path bridges the gap between knowledge and knowing” (Brown, 2006). Learning should be practical and applicable. This can be done via legitimate peripheral participation (LPP). Brown argues that the spirit of LPP “is that students are legitimately engaged in real work, fully participating in the technical and social interchanges and almost through osmosis are picking up not only the practice but also the set of sensibilities, beliefs, and idiosyncrasies of this particular community (of practice). Learning and joining this community simply go hand in hand; learning happens seamlessly as part of the enculturation process. Indeed, learning and joining become inseparable as students
move from being peripheral members to being more central members of a community of practice” (2006).

In LPP, students do more than learning; they are actively engaged community members. Instead of learning how to react to singular, controlled instances, learners can function as reflective practitioners. Donald Schön’s concept of reflective practitioners is grounded in the notions of knowing-in-practice and reflecting-in-action. Knowing-in-practice applies the idea: “as practice becomes more repetitive and routine, and as knowing-in-practice becomes increasingly tacit and spontaneous, the practitioner may miss important opportunities to think about what he is doing. Through reflection, he can surface and criticize the tacit understandings that have grown up around the repetitive experiences of a specialized practice, and can make new sense of the situations of uncertainty or uniqueness which he may allow himself to experience” (Schön, 1983).

Reflecting-in-action occurs “when new situations arise in which a practitioner’s existing stock of knowledge - their ‘knowing-in-action’ is not appropriate for the situation. It involves reflecting on ‘knowing-in-action’. ‘Reflection-in-action’ is a process through which hitherto taken for granted ‘knowing-in-action’ is critically examined, reformulated and tested through further action” (Gilbert, 1994).

By implementing Brown’s LPP and Schön’s reflective practitioner concept, members of communities are able to learn actively while simultaneously gaining skills to solve other problems. The zome art piece, as envisioned, thus triggers learning from both a scientific and
social standpoint. These analytical skills can be applied to a multitude of community-oriented problems and issues. Learning is not optimal under the traditional model of one-way flow of information; learning is a multifaceted avenue.

1.5 Design Goals for the Zome

Based on these antecedents for effective, collaborative learning as expressed above, our design goals for the zome are to:

1. Facilitate interactions between each participant and the art, in part, by making the programming of the zome as transparent as possible.

2. Inspire interactions between participants to catalyze meaningful communication with one another, potentially through game play.

3. Help the participants have fun making connections between their concepts of art and technology.

4. Accommodating different states of being by creating a safe, comforting space that acknowledges the diversity of physical, mental, and emotional states that participants have as they experience the art.

5. Promote sustainability and an awareness of environmentally conscious choices in construction and outfitting.

6. Support an active process of engagement with the art and technology, transforming bystanders and audience members into participants and performers using the concept of the “funnel”.

The process for design that was used integrates a methodology for implementing a community of practice, incorporating an assessment of the technologies and the environment. (Radziwill, 2008)
1.5.1 Facilitate Interactions between Each Participant and the Art (Goal 1)

The concept of a zome naturally supports the realization of each of these design goals. Inspired by architect Buckminster Fuller, Baer (1970) originally conceived the zome structure to utilize a greater area than polyhedral structures, enhancing their attractiveness and aesthetic value. The open structure of the zome contributes to a natural tie-in with the environment, exposing not only the interior of the zome (and thus its participants) to the weather, but also sensitizing participants to their connections with nature. (Clarke & Button, 2011)

The four fundamental design principles expressed by Williams (2008) to stimulate engagement between the participant and the artwork will be applied. These are contrast, repetition, alignment, and proximity. The structure, while designed geometrically for structural soundness, will also require these elements for peaked user interest. Alignment, or the structure’s lines, provides a sense of understanding. Horizontal and vertical lines provide stability whereas diagonal lines create dissonance. Balance in the structure’s geometry with physical appearance will invite users to become involved. The inclusion of patterns in cutouts with intersecting and diagonal lines can leave viewers feeling off-kilter that can induce a heightened reaction to the piece; evoking communal discussion and involvement.

The zome integrates audio and visual to display the frequency and amplitude of music. The more people that enter the structure, the louder an audio track becomes. LED lights also display the frequency and amplitude of the audio. These triggers to senses engage people by entertaining
via technology. However, the opportunities to recognize the patterns and make associations from the sensory factors of the zome provide an avenue for discussion and engagement.

1.5.2 Inspire Interactions between Participants (Goal 2)

The zome, as an interactive nexus that (by design) combines awareness of environment, immediate sensory experience, and a vehicle for exploring meaning, provides stimulation that people traditionally seek from technology while simultaneously catalyzing face-to-face encounters. By responding to the motions of participants inside the zome, the zome will encourage people to engage with one another to unlock approaches for controlling and manipulating the sound and light.

Neil Postman postulated the threat of television as a force for shaping human interaction in the 1980’s. Aldus Huxley’s warning -- that humans will cease to think for themselves -- centers Postman’s thesis. This dystopian threat can be extrapolated to today’s human-technology and human-human interactions, based on McLuhan's ideology of ‘The Medium is the Message,’ emphasizing consideration of the role of media in shaping interactions. Federman (2004) clarifies the concept stating, “we can know the nature and characteristics of anything we conceive or create (medium) by virtue of the changes - often unnoticed and non-obvious changes - that they affect (message.)” Simply, the message should be understood via its vehicle of delivery. However, Postman claims that ‘The Medium is the Metaphor.’ Messages are too concrete in meaning, whereas a metaphor defines special circumstances pertaining to that metaphor. Each metaphor provides a different perspective on the world; "whether we are experiencing the world through the lens of speech or the printed word or the television camera,
our media-metaphors classify the world for us, sequence it, frame it, enlarge it, reduce it, color it, argue a case for what the world is like" (Postman, 2006). The mode of delivery has the ability to alter the message and control what aspects are delivered. The zome combines audio and visual cues to deliver its message. While there is an inherent message (the understanding of the visual patterns relating to the audio construct), the zome also fosters communication, because discussion is necessary to discover the inherent message. By providing an initial opportunity for communication on common ground, the zome presents the opportunity for further discussion as a relationship has been formed.

Turkle’s *Alone Together* analyzes the potential threat of the evolving relationship between human and technological interactions. Human dependence to technology is propagating to a time of ‘aloneness’ in a hyper-connected environment. Society values constant connectivity; generations are ‘growing up tethered.’ Instead of technology fostering communication, people are removed from reality. The zome utilizes technology in a meaningful way to bring about a return to shared experiences. These shared experiences form the foundation for a return to meaningful human-human communication.

### 1.5.3 Design for Fun (Goal 3)

Today’s society is driven by a craving for fun and excitement, accentuated by the ubiquitous role of marketing in modern culture. “Fun-filled experiences are playful and liberating—they make you smile. They are a break from the ordinary and bring satisfying feelings of pleasure for body and mind.” (Shneiderman 48). As a result, “design for fun" should be at the forefront of an intervention designed to stimulate participants’ interest in and proficiency with STEM
subjects. While the zome can inspire conversation and interaction, it will only be utilized if it invigorates fun. Anderson acknowledges this idea of fun design in his book *Seductive Interaction Design*. He notes the importance to “design interactions that are more interesting and playful--interactions that engage people both intellectually and emotionally. This leads to experiences that do more than merely work, they delight people” (Anderson, 2011).

Not only does fun design engage people, but there are psychological benefits to it as well. When subjects are made to feel happy, they perform more efficiently on many levels, including creative performance (Fredrickson & Joiner, 2002; Andersen, 2011). Being in a good mood is also connected with enhanced creative problem-solving skills, and has been known to help people see more associations between concepts. Anderson also notes the benefits of pattern recognition in activities, going as far as to indicate that our brains experience a drug-like high when connections are made.

By including *patterns* and elements of patterns into the development of the visual stimulus from the zome, people are more engaged because their brains are driven to solve the pattern. This follows from the Gestalt theory of art, which posits that the whole is greater than the sum of its parts: the whole emerges, the mind seeks to avoid uncertainty, and people are naturally geared towards recognizing similarities and differences. (Chang et al., 2007) Pattern recognition allows people to “associate this stimulus with things we’ve encountered before…. [and] recognize how a new idea relates to your existing mental model of the world” (Anderson, 2011) following the Gestalt principle of similarity. The inclusion of patterns thus makes the zome approachable,
because the patterns can be associated with each participant's previous interactions with both art and elements of nature.

### 1.5.4 Accommodating Different States of Being (Goal 4)

Research indicates that “participation in community arts projects will help people with mental health problems gain wider social networks, understand and deal with their mental health issues better and gain confidence and self-esteem” (Hacking et al., 2008). These gains can apply to overall communities though as Matarasso claims: “Participation in the arts does bring benefits to individuals and communities. On a personal level, these touch people’s confidence, creative, and transferable skills and human growth, as well as their social lives through friendships, involvement in the community and enjoyment. Individual benefits translate into wider social impact by… promoting contact and contributing to social cohesion. New skills and confidence can be empowering as community groups become more (and more equitably) involved in local affairs. Arts projects can strengthen people’s commitment to places and their engagement in tackling problems…. They have the capacity to contribute to health and social support of vulnerable people, and to education” (1997).

These different states of being can be unified via participatory arts. All types contribute to society; a participatory art piece creates a location for communities to gather. Participatory arts are “effective at drawing in… bystanders, skeptics, and even adversaries… [because] they trade in meanings” (Matarasso 1997). Unlike other communal activities, arts “help people think critically about and question their experiences and those of others, not in a discussion group but
with all the excitement, danger, magic, colour, symbolism, feeling, metaphor and creativity that the arts offer” (Matarasso 1997).

The zome provides a space that invites people to become engaged in the community. People enter the structure with different backgrounds and needs, but they leave with a common experience. This shared connection ties people together; thus, creating a united community.

### 1.5.5 Promote Sustainability and Engagement with Environment (Goal 5)

According to an Energy Star article entitled Learn About LED Bulbs, “when designed well, LED lighting can be more efficient, durable, versatile and longer lasting” than traditional lighting conventions. LED lights require less energy and typically last longer than incandescent/halogen bulbs; therefore, LED bulbs have less of a footprint on the environment from an energy stance. Ultimately, the zome will be powered via solar and wind energy. This will offset the cost of electricity, which releases 1.8 pounds of CO₂ per kilowatt hour delivered according to TheCO2List.org.

Regarding environmental impact, the design of the zome follows the *silver principle*. This principle occurs naturally in the environment; thus, a more natural design occurs. Also, by cutting out portions of the panels, more natural light is able to flow into the structure and the natural environment can be seen from within the manmade structure.

The use of plywood for the final structure does include issues with minimizing the carbon footprint. Plywood is produced with a multitude of chemicals; however, in 2004, the EPA
released a report detailing that plywood manufacturers would have to implement NESHAP (National Emission Standard for Hazardous Air Pollutants) regulations in order to reduce Hazardous Air Pollutants (HAPs) from being released into the environment during plywood manufacturing (EPA, 2004). NESHAP regulation “is expected to reduce HAP emissions by 11,000 tons per year in the third year after its issuance. The rule is also expected to reduce VOC emissions, measured as total hydrocarbon, by 27,000 tons per year, PM10 emissions by 13,000 tons per year, and CO emissions by 11,000 tons per year in the third year” (EPA, 2004). According to TheCO2List.org, plywood releases “23 pounds CO₂ per 4’x8’x1/2” sheet.” Since the zome supports itself via its own geometry, no construction nails, screws, or glue are required in the construction of the zome. This reduces the environmental impact, because none of the manufacturing or chemical processes of producing these materials are required for zome construction.

The nature of visual and aural stimulations creates light and noise pollution. A 2014 article details the concern of LEDs affecting ecological systems stating due to its “large-scale adoption of energy-efficient white LED lighting for municipal and industrial use may exacerbate ecological impacts” (Pawson, 2014). LED lights are brighter than traditional light sources; therefore, the fear is they are more ‘attractive’ to critters. This could pose a threat to animals being lured from natural habitats to the bright lights of LEDs. However, the zome’s use of plywood as the structure minimalizes the light pollution, because the plywood obstructs portions of light emission.
A National Park Services (NPS) article details the impact of noise pollution on the environment. The article states that, in general, a growing number of studies indicate that wildlife, like humans, is stressed by a noisy environment.” NPS continues to state, “careful consideration of the impacts of human-generated noise on wildlife is a critical component of management for healthy ecosystems in our parks.” However, this principle can be extrapolated to any natural ecosystem -- not just those in parks. A 2012 EPA article, *Noise Pollution*, also details the health effects on humans from noise pollution: stress related illnesses, high blood pressure, speech interference, and so forth. However, the decibel level of the zome’s speakers will be mandated under the Harrisonburg, Virginia Municipal Code §15-3-2 of fifty-five (55) dBA at night or sixty-five (65) dBA during daylight hours, because it is anticipated that this will be the location of the installation at maturity.

1.5.6 Support an Active Process of Engagement (Goal 6)

The process of engagement is considered in many disciplines, including sales and marketing, for which the results of engagement can definitely impact bottom-line financial results. The ‘sales funnel’ is “often used by the sales organization to understand the flow of business opportunities” (Patterson, 2007). It depicts the evolution of a customer from prospect to qualified lead, and on through the phases of customer engagement over the long term. But as Patterson suggests, a pipeline view would be more appropriate. A pipeline-based view of the process can be seen below in Figure 1.
Figure 1. The suggested pipeline flow allows bystanders to enter at any phase. The phases are ‘audience’, ‘participant’ and ‘performer.’

The phases of engagement were obtained from a 2013 dictation by Heitlinger and Bryan-Kinns on Digital Live Art: “Bystanders do not know that a performance frame exists; an audience is aware of its existence; participants understand and can simply act within the performance frame; and performers can manipulate and perform within the frame to convey meaning” (Heitlinger, 2013). As a person progresses through the phases, they travel through the pipe. All bystanders are able to enter and flow through the pipe to any level; any engaged person is able to skip through phases. However, the highest level of interaction is performer.

A person contributes to the community at any level of engagement beyond bystander, because a shared experience is being generated. However, the further a person progresses through the phases, the more experiences become shared and the closer knit the community becomes as is supported by Brown’s concept of “learning to be.” Consequently, engagement will be assessed
by capturing direct measures, as well as conversations and interviews with participants after they interact with the zome.
Chapter 2: Zome Design and Construction

2.1 Creating the Zome

A “zome” is a hybridization of its separate entities, a zonohedron and a dome. A zonohedron is “a special case of convex polyhedron, in which every face of the polyhedron is a polygon with point symmetry” as defined by YourDictionary.com. According to the Merriam-Webster dictionary, a polyhedron is “a solid formed by plane faces” and “it is said to be convex if its surface (comprising its faces, edges and vertices) does not intersect itself and the line segment joining any two points of the polyhedron is contained in the interior or surface”. Point symmetry is a characteristic of objects that are identical when rotated 180°. The dome element is purely a way to create a self-standing structure from the geometric shape. In simple terms, the zome is a dome structure constructed from individual rhombs that each has point symmetry.

In the early stages of developing the zome, we used a Sketchup program created by Rob Bell called “Polar Zonohedron 1.0”. This program creates a polar zonohedron in a three-dimensional plane given a custom value for frequency, pitch in radians, and length. The frequency determines how many rhombs for each row, the pitch determines the angle for the next row along an individual helix, and the length is the value for each side of the rhombus. When we began our initial values were 8, \( \text{atan} \left( \frac{\sqrt{2}}{2} \right) \), and 4 respectively. We felt that having an even number of petals, or helical rows, would allow for a simple design by keeping the number of individual rhombs minimal. The pitch of \( \text{atan} \left( \frac{\sqrt{2}}{2} \right) \) was the default setting, but is based off the silver ratio. The silver ratio is a version of the golden ratio, which can be seen in many aspects of nature, such as seed/petal production in flowers. This ratio allows for the maximum number of elements to be
placed in a row, while reducing the amount of space between rows. With this in mind we kept
the default value so that the panels on our structure would mimic this result. Finally, we chose a
length of 4’x 4’ for our rhombs to create a structure that would successfully function as an
interactive art piece as seen in Figure 2.

Figure 2. This represents the 3D imaging of the zome with 4’x4’ rhombs. There is a natural
spiraling effect as one moves through the layers. This representation contains eight (8) rows,
because it is the full shape of the structure. Also, eight (8) petals make up the shape of this
structure.
After the zonohedron was created, the next step was to morph it into a dome. In order to do this, the shape was cut along the center of the shape. This allowed the zonohedron to take on the rough appearance of a dome. At this point, the structure did not have many panels, and the size of some of the rhombs would not allow multiple panels to be cut from the same sheet of material, if plywood was the material utilized. In order to correct this, the frequency was changed from eight to nine. This increased the size of the structure, since a new petal was added, and resulted in the addition of a row. This change allowed for a more appealing structural look; though the concern of waste was not entirely minimized since some of the rhombs were still too big to include multiple on one sheet. However, a potential solution of using larger cutouts in the design could resolve the issue, since this “waste” could be used to generate the connecting joints for the panels. After that was completed, a panel was removed from the fourth and sixth row, and two panels were divided in half along the fifth row in the same area. This process created an opening in the structure that will serve as an entryway inside, and will be fitted with sensors for occupancy detection as seen in Figure 3.
Figure 3. The zome was increased from eight (8) petals per row to nine (9). This increased the amount of panels and allowed for a more appealing look when panels were removed from the 4th and 6th row and two panels were cut in half from the 5th row in order to create a doorway.

Though Sketchup created a three-dimensional shape to us, it still recognized it as a two-dimensional object since no depth was given to any of the rhombs. Since the desired material is plywood, its available thicknesses and its structural integrity at those thicknesses had to be taken into account, in respect to the size of our structure. Though no physical calculations were done, the decision was based on observations of previous zome created by Rob Bell. ½” thickness was deemed acceptable both for price and durability. Once this was decided, one rhombus from each row was placed on a separate plane, and extended to a ½” thickness as seen in Figure 4.
2.2 Designing the Zome

Simple shapes were cut out of the panels to decrease opacity — these will be referred to as “cutouts” from this point forward. The cutouts allow for light to pass in and out of the zome; this integrates the zome into the natural environment. The shapes are variations on simple circles,
polygons, and triangles. “Simple” shapes are naturally occurring; therefore, the cutouts are an extension of the natural appearance as is the silver ratio to the design of the overall zome shape.

The 5th layer is composed of custom designed cutouts in SketchUp. The goal of this layer was to: 1) solidify a deeper understanding of SketchUp and 2) add a piece of individuality that ties back to the original five creators of the project. These cutouts do not implement any of the natural essence the other levels contain.

2.3 Connecting Joints

After the general structure was completed, the means for the zome to be self-supporting had to be designed, without the use of glue, nails, or a permanent bonding agent. Using previous zome examples created by Rob Bell, locking connecting joints [henceforth referenced as ‘connectors’] between each panel provided a solution. An image of a connector can be seen in Figure 5.

Figure 5. This is a vertical connector from the zome. A vertical connector angles away from the opening groove; whereas, a horizontal connector angles toward the opening groove.
These connectors are locked and held together by the force of each surrounding panel. This inspiration came from using a Sketchup program known as “Zome Builder 1.0”, which was also create by Rob Bell. This program creates a polar zonohedron based on the desired frequency and pitch, but is locked at 1’ x 1’ dimensions. This program also generates connectors that were generated for the panels at the appropriate angles needed. Then, the connectors were moved onto a new plane and scaled them up by a factor of four, so that they would be the appropriate size for the panel we would be using.

When analyzing how these connectors would fit into, or on top of, the panels, a groove can be seen on the joints as seen in Figure 6.

![Figure 6](image)

**Figure 6.** The grooves running along the top and bottom of the connector allow panels to slip into the slots. This secures the panels in place.

This groove would serve as a guide to fit and hold the panels into place. Openings were cut into the corners of each of the panels, so that the panels would be compatible with the connectors. After initially attempting to line up the panels with their respective connectors, the angle was off along the “horizontal” connector. In order to correct this, the edges of touching panels were aligned together, and the resulting angle was used to appropriately angle the horizontal
connector. Since each row panel is different, this needed to be done for each row’s horizontal connector—each differed in degrees starting at zero degrees (0°) and ending at about thirteen degrees (≈13°). After this was found, each connector was altered with the new angle and edited to keep the three-dimensional shape closed as seen in Figure 7.

![Figure 7](image)

**Figure 7.** These two horizontal connectors (as noted by their inward angle), represent horizontal connectors at two different rows. Depending on the row, the angle of the horizontal connector ranges between zero degrees (0°) and about fifteen degrees (≈13°).

Since the silver pitch was used determine the position of the new panel in each helix, we felt that assuming the vertical connector was correct would allow us to avoid making unnecessary alterations.

### 2.4 3D Printed Model

A prototype of the zome allows for testing of the structural soundness and sensor integration; therefore, we used a 3D printer from the rapid printing lab at James Madison University to generate a prototype. Given the available printers and budget, a Makerbot Replicator II was used to print the components. The next step was exporting the Sketchup files into a 3D printer usable format (STLA). According to the Department of Scientific Computing at FSU, STLA “stands
for stereolithography, and indicates that the primary purpose of this file format is to describe the shape of a 3D stationary object. Stereolithography is a means of creating physical 3D models of such objects, using resin” in ASCII. The article continues to identify key aspects of STLA files, which include neither color information nor compression.

Once the file (an individual object from the zome) was exported, it was uploaded into ReplicatorG and scaled by 0.083 (this scaling factor was used, because). After dealing with minor issues, such as conversions from Sketchup and precision of the Makerbot Replicator II, each individual piece was printed and assembled to complete the prototype. The final prototype can be seen in Figure 8.

![Image of the final structure of the zome after being 3D printed]

**Figure 8.** The final structure of the zome after being 3D printed can be seen here.
Chapter 3: Sensor Design and Construction

3.1 Infrared Gate Counter

The zome’s music patterns are determined by the occupancy of the structure. Occupancy is detected via two emitters and receivers; these are infrared (IR) LED (light emitting diode) lights and phototransistors respectively. This idea derives from the concept of garage door safety sensors. Much like the garage door emits a beam that is received by the transistor, the infrared gate counter operates in the same way. Unlike the garage safety sensor, the gate counter operates with two identical emitter/transistor pairs. This is necessary, because in order to detect if a person is entering or exiting two beams must exist. Figure 9a displays the layout of the emitters and transistors with no interruption to the beams.

Figure 9a. The symbol for a light emitting diode can be seen on the left. The symbol for a phototransistor can be seen on the right. In the case of no interruption, both phototransistors are able to sense the light from the two LEDs.
As someone is entering the zome, the first beam is tripped, because the IR light from the LED cannot be sensed by the phototransistor since the person blocks it. This is designated in Figure 9b.

**Figure 9b.** As the first beam is tripped, the IR that is emitted from the diode is not received by the phototransistor. The IR light from the diode is blocked.

Once the first beam is tripped, the person continues to enter the structure. The IR emitted by the first diode is again received by the phototransistor. On the other hand, the second diode is blocked and the second beam is tripped as seen in Figure 9c.
Figure 9c. As the second beam is tripped, the LED’s IR light is unable to reach the second phototransistor and the beam is tripped.

An Arduino is connected to the circuit of emitters and receivers via the ISAT 306 Step By Step Procedures for Creating the Classroom Count System as procured from Dr. Emil Salib. This configuration can be seen in Figure 10.
Figure 10. An Arduino is connected to the circuit of emitters and receivers. The connections are noted in the image.

The code, seen in Appendix II, is uploaded to the Arduino. The code starts by defining the minimum threshold for light the phototransistor receives (in this case zero [0]). Then, the initial times for the two beams are set at zero [0] as seen on lines 2 and 3 of the code; the initial read and input are also set to zero [0] as seen on lines 4-7. The setup is started on line 10 and the bit
rate of transfer is set to 9,600 baud on line 11. The loop is initiated on line 14. Read1 correlates to the Analog 0 read on the Arduino (in this case the second receiver). Read2 correlates to the first receiver on the Arduino at Analog 1. Line 18-21 declares that if the receiver is detecting less than or equal to the minimum threshold, the time should begin to increase for the second emitter/receiver pair. Lines 23-26 function in the same way as the previous lines, but it is for the first emitter/receiver pair. Line 28 declares that if the amount of time associated to the second receiver is greater than the amount of time recorded by the first receiver and the first receiver’s time is not at zero (so the person has tripped the first beam and continued through the entrance allowing the beam to reconnect), then the occupancy count will auto increment by one (Lines 32 and 34)--essentially a person is entering the structure. Lines 38-50 operate the same as Lines 28-36; however, it is the opposite beams being tripped--essentially a person is exiting the structure.

3.2 FFT Light Flows

Based on the Instructable “Raspberry Pi Spectrum Analyzer with RGB LED Strip and Python” by Scott Driscoll, lights and music can be integrated into the zone via a Raspberry Pi. A Raspberry Pi is used as the controller for the music and lights. A Raspberry Pi is a microcomputer, which is able to interact with the physical world via its 17 General Purpose Input/Output (GPIO) pins. The GPIO pins are used in this case to take input from the IR gate counter and to output power to the LEDs used for the lightshow. Figure 11 shows the Raspberry Pi prior to any configuration. The GPIO pins can be seen along the edge adjacent to the yellow RCA Video jack. Note the GPIO pins are only 17 of the 26 pins in the main header, the rest are for power and ground.
Before the Raspberry Pi can be used, it must have an operating system (OS) installed on an SD card. "New Out Of the Box Software" (NOOBS) was used to install the Raspbian OS. The NOOBS Setup tutorial via Raspberry Pi was followed in order to install NOOBS and subsequently Raspbian.

**Figure 11.** Raspberry Pi.
LightShow Pi was then installed on the Raspberry Pi. The purpose of LightShow Pi is to perform a Fast Fourier Transform (FFT) on the digital components of the audio files in order to display frequency and amplitude via LED lights connected to the Pi. The simple Getting Started tutorial via LightShow Pi was followed in order to install the program.

By default, LightShow Pi is configured to divide the song’s frequencies into 8 channels. Each channel is turned on or off if the amplitude for that channel rises above or falls below a defined threshold. When the threshold is exceeded, the LED associated with that channel is lit with an intensity proportional to the amplitude. As the Raspberry Pi has digital pins, this is accomplished using pulse width modulation (PWM). PWM gives the illusion of light intensity by rapidly turning on and off the LED. The more frequently the LED is switched on the brighter it appears to be and vice versa. Low amplitudes result in lower values being passed to the PWM function, which results in a lower intensity, and higher amplitudes result in higher intensity.

With LightShow Pi installed, the Raspberry Pi needs to be connected to the lights it will control. Figure 12 displays the wiring of the LEDs to the Raspberry Pi.
A female-to-male header was used to connect the Raspberry Pi to a breadboard. 8 LEDs, corresponding to the 8 channels or frequency bands, are wired to their respective GPIO pins—as followed in the *LightShow Pi Hardware Setup* tutorial by Cory Dorning. The negative lead of each LED is grounded with a 220 Ohm resistor to prevent them from burning out. The positive lead of each LED is connected to its corresponding GPIO pin.
At this point running LightShow Pi works. From the LightShow Pi directory, the command

```bash
sudo python py/synchronized_lights.py --
file=/home/pi/lightshowpi/music/sample/ovenrake_deck-the-halls.mp3
```

successfully plays *Deck the Halls* and displays the FFT results via the eight (8) LEDs.

However, the lightshow needed to be scaled up. Therefore, an independently controllable RGD LED light strip was added to the system as outlined in Driscoll’s Instructable. Driscoll’s custom synchronized_lights_LED_strip.py script was modified from five (5) columns to seven (7) in order to better fill the space of the zome. The changes can be noted in Appendix III. The lights were then cut to the appropriate seven columns and secured to a laminate piece. The lights were organized as seen in Figure 13.
Figure 13. The lights were organized into seven columns. Column 1 represents the highest frequency; Columns 2, 3, and 4 represent lower frequency ranges respectively. The pattern of the diamond was selected to mimic the rhombs comprising the zome panels. Columns 4 represent the lowest frequencies. Columns 3 represent the next highest frequency. Columns 2 represent the next highest frequency after that. Column 1 represents the highest frequency being rendered in the display. Then, a piece of Plexiglas was scored and placed on top of the laminate. This provided a container for the lights while protecting them from direct contact. This setup can be seen in Figure 14.
Figure 14. This container of lights is a piece of laminate with wires running under the laminate. The lights are secured to the laminate. A Plexiglas board was secured to the top of the laminate.

3.3 Music and Light Controller based on Occupancy

With functional FFT representation via LightShow Pi and functional occupancy counting via Arduino, the two are now integrated into a single application. The first step is to enable the functionality the occupancy count will have on the Raspberry Pi. The occupancy count determines the volume of the music. To change the volume of the Raspberry Pi, the command

```
amixer cset numid=1 --#%
```
is used. The ‘#’ is substituted with the desired percentage of volume level. As seen in Lines 1 and 6 of Appendix IV, the os library can be imported and used to execute system commands from a Python script. With the ability to change volume via Python, the Raspberry Pi can take input from the IR sensors and use it to affect the environment of the zone.

The counting is then moved from the Arduino (as done via the sketch in Appendix V) to the updated change_volume.py script—as seen in Appendix VI. In this setup, as seen in Figure 15, the Arduino is being used as an analog to digital converter.
Figure 15. The Arduino processes an analog input and converts it to a digital output. This output is then processed by the RaspberryPi to control the volume levels based on occupancy.

It may be feasible to do away with the Arduino entirely but further investigation must be done before this design decision is made. The values from the receivers may or may not be too low to
accurately read using the GPIO pins’ digital input. Arduino is capable of analog input, which works well with small changes in voltage. The Arduino outputs a digital signal to the Raspberry Pi. As seen in Lines 36 and 46 of Appendix VI, the Arduino performs a digital write out of one of two pins instead of updating the counting variable. This digital signal is received by one of two digital input pins on the Raspberry Pi and change_volume.py increments or decrements the occupants count as seen in Lines 21 and 23 in Appendix VI. However, the signal must first pass through a voltage divider to step down the 5V output by the Arduino to an acceptable 3.3V for the Raspberry Pi. Each output pin has its own voltage divider as seen in Figure 16.

![Figure 16](image)

**Figure 16.** The voltage divider for each sensor allows for the 5V output from the Arduino to be received at 3.3V as per specifications for the RaspberryPi.
Three 1,000 Ohm resistors are used per voltage divider. Voltage Dividers, a tutorial at sparkfun.com, was used as a reference for constructing the dividers. Voltage dividers use resistors in series to output a voltage that is smaller than the input. The values for the resistors were calculated using Equation 1.

\[
V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2}
\]

**Equation 1.** Finding output voltage from a voltage divider.
Chapter 4: Integration of Zome and Sensors

The zome functions as the vessel of the interactive art piece while simultaneously being art itself. The Arduino and RaspberryPi control the light flows and music within the structure. The combination of zome and sensors results in an art piece that inspires engagement and interactivity.

Based on the prototype, the occupancy sensors for the full-scale zome would be connected to the doorway with one external and one internal to the depth of the panel at an estimated height that would most commonly cause the beams to be broken at the average torso height. As long as the beam is broken at or above pelvic level, the beam will not accidentally be tripped twice by the crossing of one leg followed by a delay of the second crossing. The lights would form the floor of the zome. This provides an uninterrupted view of the cutouts in the zome. It also places the pattern of lights in a plane that can be viewable from any position inside of the zome.

Upon entering the zome, a person is surrounded by panels allowing varying levels of light to enter the zome. The person can still see the outside world, but he or she is contained inside the piece. The piece arrests attention on all sides. The walls of the zome surround above and around. Music plays throughout the structure resonating within a person—whether bystander or performer. The floor holds the lights that visually represent the aural stimulation.
Chapter 5: Assessment and Future Considerations

The zome is a flexible and changing art piece. The very nature of this zome, by design, is to support its evolution from an interactive to a fully participatory art installation. For that reason, changes and modifications must be built into the core design of the art itself.

Communities are made-up of audiences and performers; this art piece provides the common ground to pave the way for community building. It is essential to assess the engagement of participants as a consequence of their interaction with the zome. This will be achieved primarily by capturing conversations and conducting interviews. These discussions would capture the success of engagement, but success is not determined by discovering the pattern of light flows or expressing an opinion on a particular shape of geometric cutout. Success must be qualified by the role of the installation to cultivate a deeper feeling of community or an invigorated passion for coding. The art piece thus proves “useful” by attaining any of the pre-defined goals at any level of engagement.

Previous studies can inform the assessment strategy. For example, Glowacki (2013) discovered that in the assessment of danceroom Spectroscopy, "People were simultaneously confused by and attracted to seeing rather abstract energy representations of themselves, compared to the more literal video-game type representations to which they are accustomed. People seemed to have had the least confusing and most engaging experiences when their initial encounters with [the installation] presented them extremely literal, person-shaped energy fields embedded in a system comprised of only a few atoms with easy-to-interpret collision sounds." That is, people
reported increased satisfaction based on 1) knowing that they were not seeing something abstract, but instead reflected by physical world, and 2) if they received some instruction prior to interaction with the installation to describe what was happening and what they could do with it. Open-ended discussions must be supported to uncover outcomes like this. Furthermore, this suggests that prior to interaction with the zome, participants must be informed about the basic function of the zome and how their actions influence the quality of the sound and light show. Furthermore, programming of the sound and light show must be made transparent, so that it is clear to participants exactly what commands are being generated in response to their movements.

Upon deployment, the art piece will need to be assessed based on its ability to satisfy each of the original design goals, that is, to: 1 & 2) facilitate interactions (with the zome and with others), 3) provide the means to have fun while connecting art and technology, 4) accommodate different states of being, to support active involvement by diverse participants, 5) promote sustainability and environmental awareness, and 6) support active and changing levels of participants' engagement with the art piece (and consequently other participants as well). Assessment must be performed every time a participant interacts with the zome.

Assessment mechanisms, centered on capturing conversations and conducting interviews, must address each of these goals. Table 1 outlines possible tactics for ensuring that each of the design goals is addressed in the assessment.
Table 1. Each of the design goals is implemented with assessment questions for each design goal. This is to evaluate the success of the art piece in achieving each goal.

<table>
<thead>
<tr>
<th>Design Goal</th>
<th>Assessment Questions for Interview and Discussion</th>
</tr>
</thead>
</table>
| Facilitate interactions with zome itself         | • How did your movements alter the sound and light show? Did you notice any patterns?  
• Were there any responses that you expected the zome to make to your presence, but it did not?  
• Did you interactively program or change the nature of the zome's sound and light show because of your experience with the zome? |
| Facilitate interactions with others              | • Did you interact with anyone else in the zome?  
• Were there any barriers that prevented you from interacting more fully with the other participants in the zome, and if so, how do you feel they could be removed? |
| Have fun while making connections between art and technology | • Did you have fun?  
• Would you visit the zome again?  
• Were you able to gain any new skills in, or awareness of, electronics and programming? What were they? |
| Support diversity in participants and different states of being | • Did you feel comfortable and welcome in the zome?  
• Were there any barriers that prevented you from interacting more fully with the zome itself, and if so, how do you feel they could be removed? |
| Support active and changing levels of participation | • What are some things you would have liked to do to extend the artistic nature of the zome, but felt that you could not, and why? |

In addition to continuous development of the zome and its capabilities in response to participant feedback and analysis of the assessments, the zome itself can be continually improved to reflect the core value of environmental sensitivity and sustainability. For example, one crucial goal for the zome's future design is to make it independent of the power grid. If the zome was provided
with energy by solar panels, wind turbines, or similar mechanisms, a new dimension will be added to the art piece to stimulate an awareness of the environment and sustainability considerations. Not only will it promote eco-friendly construction, but these choices will also prompt additional discussions about replacing environmentally toxic power sources with natural, more sustainable ones. In addition to stimulating STEM learning through STEAM, the zome will provide the opportunity for students to reflect on making better choices for the environment in general.
Appendices

Appendix I: Materials

Hardware

Zome

- MakerBot Replicator 2 - https://store.makerbot.com/replicator2.html

Sensors

- RGB LED Light Strip - e.g., http://www.theledlight.com/flexible-RGB-strips.html
- Breadboard(s) - http://en.wikipedia.org/wiki/Breadboard
- 5V 10A Power Supply

Software

Zome

- ZomeBuilder 1.0 - https://www.facebook.com/zomebuilder
- SketchUp - http://www.sketchup.com/
- ReplicatorG 3D Printing - http://replicat.org/

Sensors

- LightShow Pi - http://lightshowpi.org/
- RPi-LPD8806 accelerator for LEDs - https://learn.adafruit.com/raspberry-pi-spectrum-analyzer-display-on-rgb-led-strip/speed-up-the-rgb-strip-software
Appendix II

The sketch implemented in the Arduino can be seen here. This detects the occupancy of the zone by tripping two different beams.

```cpp
const int MINIMUM = 0;
int time1 = 0;
int time2 = 0;
int read1 = 0;
int read2 = 0;
int input1 = 0;
int input2 = 0;
int occupants = 0;

void setup() {
    Serial.begin(9600);
}

void loop() {
    read1 = analogRead(A0);
    read2 = analogRead(A1);

    if(read1 <= MINIMUM)
    {
        time1 = millis();
    }

    if(read2 <= MINIMUM)
    {
        time2 = millis();
    }

    if(time1 > time2 && time2 != 0)
    {
        time1 = 0;
        time2 = 0;
        occupants++;
        Serial.println(1);
        Serial.println(occupants);
        delay(500);
    }

    if(time2 > time1 && time1 != 0)
    {
        time1 = 0;
        time2 = 0;
        if(occupants > 0)aa
```
{  
  occupants--;  
}

Serial.println(0);
Serial.println(occupants);
delay(500);
Appendix III

The `synchronized_lights_LED_strip.py` file created by Scott Driscoll was modified to display seven columns. The modifications are seen below starting on Line 76.

```
76 led_array = [0 for i in range(63)]
77
78
79
columns = [1.0,1.0,1.0,1.0]  
80 decay = 0.8
81 #this writes out light and color information to a continuous RGB LED
82 #strip that's been wrapped around into 7 columns
83
84 def display_column(col=0,height=0.0,color=Color(50,50,0)):  
85     global c
86     global columns
87     color = wheel_color(int))
88     c = c + .1
89     if c > 384
90         c = 0.0
91     height = height - 9.0
92     height = height/4
93     if height < .05:
94         height = .05
95     elif height > 1.0:
96         height = 1.0
97
98     if height < columns[col]:  
99         columns[col] = columns[col] * decay
100        height = columns[col]
101     else:
102         columns[col] = height
103     if col == 3:  
104         led.fill(color,0,0+int(round(height*5)))
105     led.fill(color,54,54+int(round(height*5)))
106     elif col == 2:  
107         led.fill(color,13 - int(round(height*7)),13)
108     led.fill(color,53 - int(round(height*7)),53)
109     elif col == 1:  
110         led.fill(color,14,14+int(round(height*9)))
111     led.fill(color,36,36+int(round(height*9)))
112     elif col == 0:  
113         led.fill(color,35 - int(round(height*11)),35)
```
Appendix IV

This `change_volume.py` script proves that the operating system can be imported and the volume of the Raspberry Pi can be changed.

```python
import os
import time

# Pause execution for 30 seconds and change the volume to a percentage of the max
time.sleep(30)
os.system('amixer cset numid=1 -- 70%)

time.sleep(30)
os.system('amixer cset numid=1 -- 90%')
```
Appendix V

The sketch on the Arduino is updated to send voltage levels to determine occupancy in order to be interpreted by the RaspberryPi. This is a modification of the sketch seen in Appendix II.

1. const int MINIMUM = 0;
2. int time1 = 0;
3. int time2 = 0;
4. int read1 = 0;
5. int read2 = 0;
6. int input1 = 0;
7. int input2 = 0;
8. int pin2 = 2; //to RPi Pin24
9. int pin4 = 4; //to RPi Pin26
10.
11. void setup() {
12.     Serial.begin(9600);
13.     pinMode(pin2, OUTPUT);
14.     pinMode(pin4, OUTPUT);
15. }
16.
17. void loop() {
18.     read1 = analogRead(A0);
19.     read2 = analogRead(A1);
20.
21.     if(read1 <= MINIMUM) {
22.         time1 = millis();
23.     }
24.
25.     if(read2 <= MINIMUM) {
26.         time2 = millis();
27.     }
28.     //Enter
29.     if(time1 > time2 && time2 != 0) {
30.         time1 = 0;
31.         time2 = 0;
32.         Serial.println(1);
33.         digitalWrite(pin2, HIGH);
34.         delay(500);
35.         digitalWrite(pin2, LOW);
36.     }
37.     //Leave
38.     if(time2 > time1 && time1 != 0) {
39.         time1 = 0;
40.         time2 = 0;
41.         Serial.println(1);
42.         digitalWrite(pin2, HIGH);
43.         delay(500);
44.         digitalWrite(pin2, LOW);
45.     }
46. }
47.
48.
49.

time1 = 0;
time2 = 0;
Serial.println(0);
digitalWrite(pin4, HIGH);
delay(500);
digitalWrite(pin4, LOW);
}
Appendix VI

The `change_volume.py` script controls the volume of the RaspberryPi based on the occupancy counting occurring on the Arduino. This is a modification of Appendix IV.

```python
import os, time
import RPi.GPIO as GPIO
GPIO.setmode(GPIO.BOARD)
GPIO.setup(24, GPIO.IN, pull_up_down=GPIO.PUD_DOWN)
GPIO.setup(26, GPIO.IN, pull_up_down=GPIO.PUD_DOWN)
redundant0 = False
redundant4 = False
redundant6 = False
redundant8 = False
redundant10 = False
occupants = 0
var = 1
while var==1:
    #Get values from arduino
    inflow = GPIO.input(24)
    outflow = GPIO.input(26)
    if inflow == 1:
        occupants += 1
    if outflow == 1 and occupants > 0:
        occupants -= 1
    print occupants
    if occupants <= 3:
        if redundant0 == False:
            os.system('amixer cset numid=1 –0%‘)
        redundant0 = True
    else:
        redundant0 = False
    if occupants == 4 or occupants == 5:
        if redundant4 == False:
            os.system('amixer cset numid=1 –75%‘)
        redundant4 = True
    else:
        redundant4 = False
    if occupants == 6 or occupants == 7:
        if redundant6 == False:
            os.system('amixer cset numid=1 –85%‘)
```

61
redundant6 = True
else:
    redundant6 = False
if occupants == 8 or occupants == 9:
    if redundant8 == False:
        os.system('amixer cset numid=1 – 90%')
        redundant8 = True
    else:
        redundant8 = False
if occupants > 9:
    if redundant10 == False:
        os.system('amixer cset numid=1 – 100%')
        redundant10 = True
    else:
        redundant10 = False
# Set a delay equal to that of arduino
time.sleep(0.5)
Appendix VII

Breakdown of section writers.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Primary Writer</th>
<th>Secondary Writer</th>
<th>Editor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Cassidy Moellers</td>
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