The Choreography of a Living Wall:
A Technique Framework that Integrates Color Theory As it Relates to Vegetated Assemblies

Masters Document

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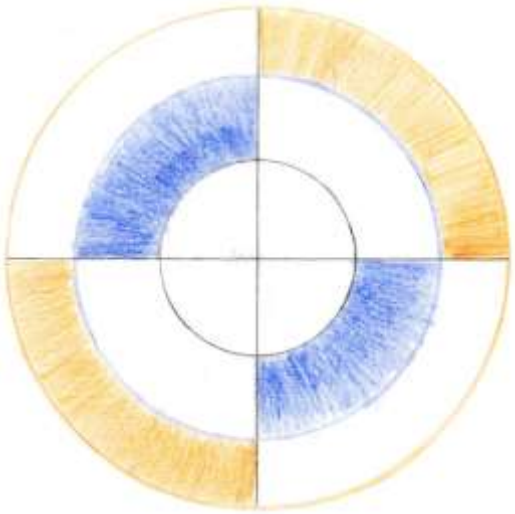

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1

Introduction: Defining the Study

Introduction

Abstract

The study is aimed at changing the way buildings are designed by creating a decision support framework (DSF) for the representation of vegetated assemblies, in this instance vegetated walls and facades using woody vine species. The scope of the project is limited to the commercially available native and nonnative plants in southwestern Virginia, and how these vine species can be selected for use as vegetated architecture.

This decision support process would provide a basis for the background reference and context for selecting vine species, support in determining representational methods for designs, and tutorial for how to use commonly used programs in studio to better represent vegetated structures and assemblies. The framework assists in selection of the plants based on appearance, color theory, and the physical limits or characteristics of the vines.

A parallel study of vegetated assemblies through the construction of a full-scale electric car garage will test the framework. The decisions made in the vegetated façade of the electric car garage will test some of the tenets of color theory as applied to vegetated walls and provide a base for further study via continued monitoring.

The decision support structure and resulting designs will show the potential vine and plant characteristics amassed in the study as they are applied to architecture. A framework such as the triad of tools used for the reference, representation, and teaching of vegetated assemblies, will demonstrate the various factors that impact the requisite decisions when designing vine covered walls and facades. All of these prototype tools combine to assist designers in the ideation of vegetated facades, and then to allow for a wide variety of vegetated assembly representations.

Position Statement

Architecture exists as an example of personal interactions with the surrounding environment. There are many different interpretations of this theme; however, the particular method I choose to subscribe to is the idea of man as a metric for the development of space and impression. This belief is not solely dependent upon the individual, but the interface the individual has with architecture and the environment, creating a dialogue that informs design.

We, as designers, people, and users all have a sense of place and connection to the environment in which we live. To design a building that is not in some way responsive to the surrounding conditions of nature is simply a lost opportunity for a more compelling intervention in architecture. This sense of place within the realm of architecture is created by the deeply personal memories and experiences from each individual. The impression that one gets from the space and its contact with the surrounding environment, should be immediate, in that way architecture shows us its worth.

This idea of an innate connection to the environment, termed biophilia by the biologist Edward O. Wilson, is not new. Man first existed in nature and then used architecture to provide shelter and a sense of place. This harmony with nature is not only being sensitive to the environment, but also sensitive to the cyclical methods that nature employs and how these cycles can be integrated into the design of responsive architecture. It is important to understand that this style of architecture is not reactionary, but a combination of natural and man-made stimuli to create space as a *designed response*.

The past, present and future must be present in the mind of the designer as a continuum. This creates perspective and context against sentimental historicism, modernism and utopianism. This is not to say that the designer is solely focused in the past, but rather is aware of the past, the past that has become the present and is projected into the future. The way in which a designer operates then influences future interventions in architecture which may or may not be his own.

Therefore, the designed response is not an act that is applied to a particular project, but a habit that is maintained by the designer, ingrained into the design process. When a method, such as this sensitivity to the surrounding environment, is central to the design from the beginning, the response is stronger and more developed. This is not to say that a project must be only one pure idea. Design should have many layers that build the intensity of the design, without adding unneeded complexity.

Problem Statement

What is the method that individuals interact with process sensory input from the surrounding environment? Such sensory information can be taken into the person, transformed into useful knowledge, elaborated upon by past experiences, stored for future interactions, then called upon in times of need and used again. This process is termed cognition. Cognition can be, and is used for all aspects of living, and in philosophy there is a subset of techniques: epistemology, logic, metaphysics, ethics and aesthetics. The first of these techniques is epistemology, is mainly concerned about the areas that which can be known and their scope (NYU, 2014). Epistemology, combined with another type of cognition, meta-cognition, will prove critical to the proscriptive development of the design process supporting the prototypical tool for representing vegetated assemblies.

How do we know what we know (knowledge about cognition) and how do we know that we know it (regulation of cognition)? These are the two main components of meta-cognition (Schraw, 1998). There is also the description of design research as explained by Nigel Cross in Designerly Ways of Knowing. This method relies on seeing design as a third culture to the humanities and sciences. This third culture can also be called technology, or applied science and organized knowledge combined to address practical tasks. Overall, these sorts of practical tasks are not necessarily evaluated by analysis alone as in the sciences, but through the synthesis of ideas, and experiences. Design problems are often called 'wicked (Rittel and Webber, 1973). This means that they are not as defined and compartmentalized as other research questions, often acted upon by many different external forces. These problems must be re-defined and re-evaluated by the experience and tools available to the designer. This begins to place limits on the design, generating a possible outcome or design solution.

To tackle these 'wicked problems', vegetated assemblies will engage color theory and apply its synthesis to the representational tool. Phenomenology is a theory of knowing that contends that the observation of phenomena is different from perception and judgment. Instead of discretely evaluating through perception or rationalizing through judgment, an individual experiences ones' surroundings as a world or an object outside the observer and then internalizes these experiences; that we are a summation of our experiences and knowledge. From this basis about understanding cognition and meta-cognition the

prototype tool will serve as a method for allowing designers to experience design in a different manner in relation to color theory, informing their design decision-making process.

With concerns about environmental impact of buildings persisting, new methods and theories of construction continue to develop; however, this concern should not become dominant to the aesthetics of the design. Aesthetics should be in a dialogue with environmental design concerns allowing for each to complement the other. How do we meld the science of plant biology with environmental design? Specifically, how can the use of plant biology and color theory interact with and respond to the building envelope? The building envelope is a very broad topic; however, in reference to nature, one type of building system can be called to the forefront: vegetated assemblies.

The design of vegetated assemblies should be responsive to the building's site both in vegetation used and in color theory, in order to improve the interaction and experience between the user and the building and climate. However, this study is looking for regional expression by using specific plant biology and color theory for southwestern Virginia. If the study were to encompass all types of plants and their respective biology, it simply would not be feasible. Therefore, the climate and location will limit the study to plants viable to the Appalachian Mountains as a demonstration of a more wide-ranging future study.

So how can a regional interpretation of nature be brought back to the constructed environment, using the very walls that form it? The ancient gardens of the Egyptian and Mesopotamian civilizations and the Chinese in medieval times show the desire to bring vegetation back to the constructed environment (Hongxun, 1982; Osmundson, 1999; Shepard, 1967). Others contend that in more modern time vegetation was used as a wellness and stress reduction of those in the constructed environment (Parsons, 1991; R. S. Ulrich, Dimberg, & Driver, 1991). Biophilia takes this further developing on the hypothesis that there is a genetic predisposition to nature that creates the innate desire for a connection with nature (Darwin, 1877 (2010); Wilson, 1984). What is the formative role of vegetation on sustainability and green architecture outside of energy conservation? Vegetation has the ability to give a sense of connection back to nature not commonly found in constructed environments. In the urban environment there can be a lack of vegetated spaces for those living in cities. Architects have, and use this opportunity to develop ideas and design concepts applicable to vegetated walls and facades, creating living buildings. These vegetated facades can be both decorative and integral to the building itself. Therefore, biophilia

can serve as an underlying driver for the inclusion of vegetated assemblies in the constructed environment, such as walls, buildings, and other architectural structures.

From all of this, what Nigel Cross mentions about synthesis being important to architects and designers is critical. From all of these subsets of different problems, a problem reveals itself: how can designers synthesize vegetation/plant growth, color theory and design decision-making to be better integrated into the design process of ideation, representation, and iteration?

Purpose of the Study

Specifically, this research is intended to contribute to a larger body of knowledge on how color theory is connected to plant biology for vegetated building assemblies on architecture in a local climate of Southwest Virginia and how this can be synthesized to create a useful prototypical representational tool for the display of vegetated assemblies. The aim is to enhance a quality of aesthetics in the design and implementation of vegetated building assemblies. However, the question of color theory in relation to plant biology in vegetated assemblies is not proven or disproven, but observed meticulously in an effort to amass information on its characteristics. Therefore, intent of the study is to consider and examine these assemblies as architectural elements of the visible world in order to purposefully design aesthetically pleasing objects. This is what designers can give to users by taking into account and carefully crafting the stimuli in a space. We as designers need to continue to think, to contemplate, to understand. We must think about the phenomena and its worth. According to Rudolf Steiner, in Goethe's (1749-1832) scientific writings he believed that thinking should direct observation (Steiner, Goethe, & Barnes, 2000). If thinking about our observation is necessary to a more complete understanding of a given situation, then our interaction with a phenomenon is influenced by the knowledge that we both have and do not have. The purpose of studying the phenomena of color theory in vegetated assemblies is to then be able to implement such knowledge later in design. The core of the study is how vegetated wall assemblies, through their plant colors and materials, are influenced by color theory and how that influences their aesthetic design. From this core, a simulation approach to be able to visualize the possible system will be developed.

This simulation approach or prototype representational tool trough the design process would not be a singular mandated method for making designs, but a suggested guide through a designer's process. In this way the proscriptive tool would impact the more prescriptive design method and philosophy that the student has begun to develop during their studies, or that the professional has developed through experience. The tool should not be prescriptive by imposing a particular method of design, but rather be proscriptive, describing a method that could be used and then allowing the designers to make decisions based off of the representational tool. The tool would not make the decisions for them as that would negatively impact the ideation process.

Architectural design is inherently a decision-making process of which ideation and representation are at its foundation. Designers typically move from ideation to representation and then to iteration. Moving from the more abstract step of ideation, representation allows the architect to move from an idea to issues of quality of space, materials, construction, or in this case color theory. The representational tool can serve as an outlet, an extension of the representational process, allowing for a design in its totality, not simply the ideal conditions. The representational tool would allow designers to test their designs to better understand their implications and allow clients to visualize a potential design to support for construction. This research has at its foundation this evolution of this process. Figure 1 is a map for the theoretical placement of the study, attempting to balance proscriptive methods that impact the prescriptive methods with through phenomenology.

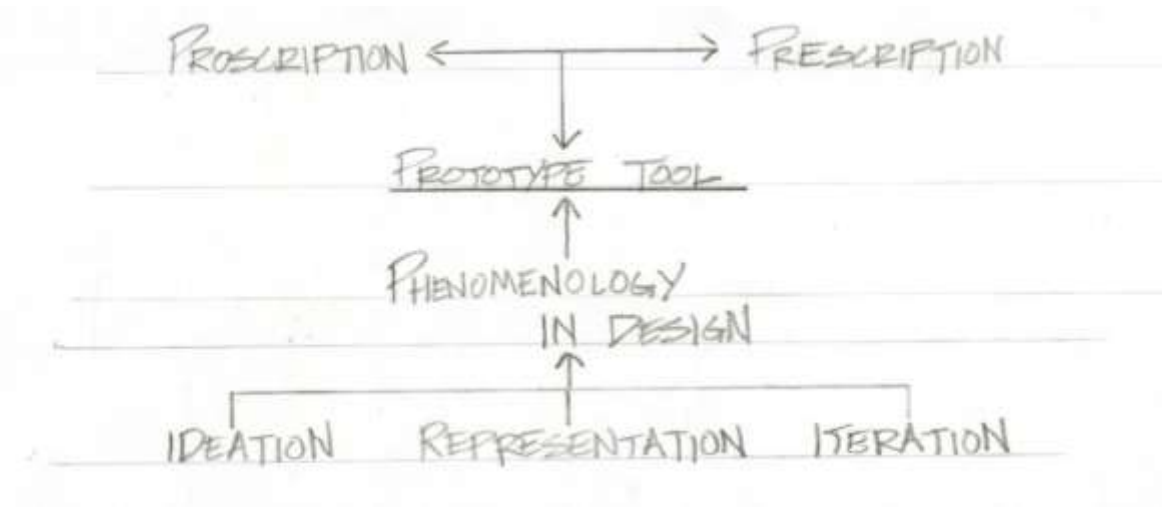

Figure 1: Proscriptive and Prescriptive Methods to influence the prototype tool

Research Questions

The inquiry is: how we as designers begin to use the aesthetic that is created when plants over time interact with each other spatially and chromatically in vegetated walls and how can this be used in a representational tool to synthesize vegetation/plant growth, color theory, and design-decision making. This research will attempt to discover the characteristics of vegetated elements in architectural design in reference to color theory and plant biology. When selecting plants for vegetated walls what are questions to consider? We need to consider what kinds of plants are adaptable to vegetated assemblies. We need to consider if there are compatibility issues between types of plants selected in the assembly. Finally, we need to consider what the possible implementation issues for plants that are adaptable in vegetated walls, such as watering, pollination, or root depth. Other plant characteristics that need to be considered when implementing vegetated facades include: a plant's origin, range applicable hardiness zone, climbing mechanism, resiliency to climatic conditions, weight, profile, and texture. These questions will be applied to vegetated facades to determine the specific regional expression in a Southwestern Virginia climate based on useful flora. The characteristics of plant biology coupled with color theory influence the designed space. In order to know how these characteristics are influencing color theory in vegetated assemblies, the plant biology of the flora needs to be observed or obtained.

Color theory is not simply the color wheel or feelings associated with colors. Color theory is heavily influenced by the infinite nature of color. Color within light resides in a spectrum of wavelengths, with each color blending into the next. In the spectrum, light displays itself and the face of nature, informing us of the characteristics of surrounding objects. The resultant color is at all times specific and characteristic of the object, yielding significance. By understanding the relationship aesthetics has with these theories, it will allow for a better integration of aesthetic design with vegetated building assemblies through synthesizing vegetation/plant growth, color theory, and design decision-making.

Definition of Terms

The study has four main concepts: aesthetics, decision theory, color theory, and plant biology. This study will be engaging aesthetics from a phenomenological view. This philosophy is the study of

consciousness from personal observations. The critical experience of phenomena is in reference to an object by its content or meaning in reference to our own notions and thinking.

Aesthetics is of or relating to beauty. However there are many different kinds of interpretations of this beauty. Immanuel Kant believed aesthetics to be a subjective experience of beauty, universal in function only when disinterested (Kant & Walker, 2008). To Friedrich Schiller, aesthetic appreciation of beauty is the most perfect reconciliation of the sensual and rational parts of human nature (Schiller & Snell, 2004). As expected, methods of thinking or expression that are subjective in nature have many different definitions or processes when attempting to understand the subject matter.

Decision theory or decision-making theory is centered on the making of decisions. Decision theory resides in the theoretical unknown or making a decision in response to a problem without a clear, single answer (Hansson, 2005). While this definition of decision theory is more general, in design, another type of theory is present: design support structures (DSS). These structures are less about making the final decision for the designer and more for supplying the designer with information in which to make an informed decision (Cross, 2007, 2011). Therefore the experience of the designer brings works with the DSS to design more effectively. The design support structure that will become the prototype representation tool will work with the designer to help make decisions but not make the decision for them.

Figure 2: Placement of Prototype tool in the design process

Color theory, according to Goethe, is a guide to the nature of colors and how these colors are perceived by humans (Steiner et al., 2000). He understood color as how the phenomena of color are perceived and was less concerned with the analytic properties. This is only one view of color theory and this concept is expounded upon in the literature review.

Plant biology, also called botany or plant science, is the scientific study of plants, including their physiology, structure, genetics, ecology, distribution, classification, and economic importance. In relation

to plant biology, according to Edward O. Wilson, biophilia is an appreciation of life and the living world (Kellert & Wilson, 1993). This unspoken but deeply connected bond with nature people have is how plant biology and the expression of vegetation on the envelope of a building, will be combined with color theory when using vegetated building assemblies to develop a new stance on their synthesis.

Finally, the building envelope is the physical separator between the interior and exterior of a building, for example a wall, floor, roof, fenestration or doors. The building envelope serves to keep occupants comfortable again undesirable exterior conditions. Depending on the climate, building envelopes can have a wide variety of implementations, from being almost a shell to being thin skin. The building envelope is where vegetated assemblies are usually located; on the exterior of a structure. Some vegetated assemblies, when cared for correctly can be on the interior of the structure.

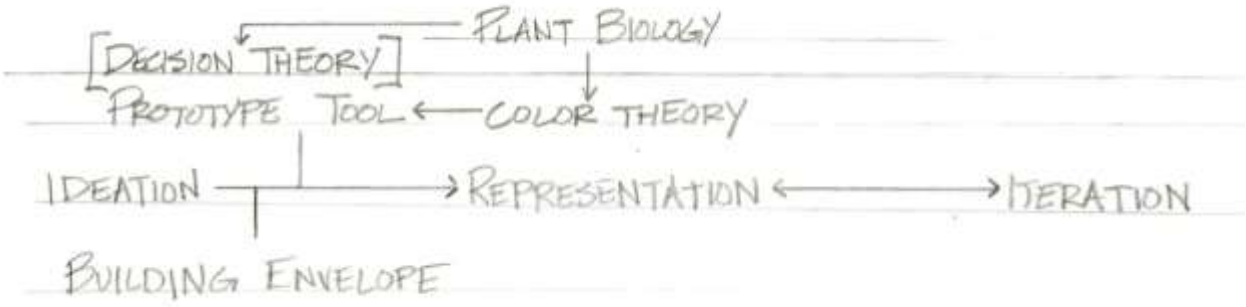

Figure 3: All themes in reference to ideation, representation and iteration

Limitations

As the study is specific to the biology of plants usable for vegetated assemblies, baseline data collected from field guides of local plants will be both quantitative and qualitative. However, much of the information collected during the study will be observed from photographic studies or mock-ups, rather than solely empirical testing from a hypothesis. It will be important to use causality appropriately and not to overreach inductions from specific observations.

Based on the main tenets of color theory and plant biology, the research is limited by the study location and the types of plants useful to a Southwestern Virginia climate: USDA Plant Zone 6. Furthermore, the colors can be variable based on the geographic location and climate of the plants

selected. Color can also change over time in plants, thus making analysis variable over time, but cyclical over the course of the year based on the seasons. As the local plant species are based on a regional macroclimate, it would not be appropriate to extrapolate all findings to all species of plants or locations. Different species of plants or plant physiology would induce different color or spatial characteristics.

Probably the most important limitation to consider is perception. We as humans perceive light and color similarly, but our reaction to these color and stimuli can vary. While perception is important, it does not invalidate the purpose of the study, as phenomenology acknowledges the inherent personal interaction that an individual can have with objects or architecture.

Procedures/Methods

There will be five main steps to the research process: logical argumentation, photographic analysis, prototyping development, immersive case studies, and a member checking or Delphi. Logical argumentation will be done from the literature review as a basis for plant selection, structure of the software to be used in the prototype tool, what the tool will provide in terms of decision support (output). The photographic analysis will determine the color characteristics of selected plants to be integrated into the prototype. The stages of prototype development will serve as a process for prototyping the representational tool based on color theory. Immersive case studies will serve as beta testing the representational tool to test its usability toward improving design decision-making. This stage will use myself and 2-3 other “designers” or colleagues to develop the tool. A final member checking or Delphi stage will be completed to gain a consensus for the positive impact on design decision-making using a maximum variance sample of 6 to 12 designers using interviews. The following chart shows the different categories these designers could reside.

Table 1: Experience and Method Used in Vegetated Assemblies

Maximum Variance Sample Experience and Method	Computer Design	Analog / Hand-Drawn
No Previous Experience with Vegetated Assemblies		
Previous Experience with Vegetated Assemblies		

The investigation of vegetated building assemblies in reference to color theory, plant biology, and relevant software will be conducted with a review of both historical and current literature. This literature review will attempt to answer some of the key questions of the study such as: what kinds of plants are adaptable to vegetated assemblies?; are there compatibility issues between types of plants selected in the assembly?; and what could possible implementation issues for plants that are adaptable in vegetated walls? All of these questions will then be analyzed based on the fundamental tenets in color theory. The software will be reviewed in both academic and professional settings.

After the literature review, a series of photographic studies centered on the key questions will be conducted to document and analyze chromatic, saturation, and visual density characteristics of the plants selected. There will also be studies of the local landscape to discover natural qualities that could be emulated in vegetated walls. This series of studies will lay the foundation for examining and amassing a larger range of characteristics of plants used worldwide.

Afterwards, computer simulation programs will be used to see if such qualities of color and density are reproducible from the characteristics uncovered in the photographic studies, as applied to useful floras. After compiling all of the necessary observations, this study will be used in conjunction with a full-scale construction of an electric car charging garage to use tenets of plant biology and color theory in design and implementation. This immersive case study will provide a method for understanding how digital representation can be used to create and evaluate vegetated facades.

This study will use two different types of digital representation techniques: Photoshop, which is a flat rasterize program; and Grasshopper, a Rhinoceros plug-in. Some other software that might be explored in the design of the vegetated assemblies could be Google SketchUp. The integral part of such modeling is to accurately reflect conditions to predict, control, or explain conditions on the site. The representational tool would accept a 3D model as input and then re-represent the elevation with the selected plants. The selection of the plants would be based on appearance and color theory. The tool would represent either one (color) plant or two plants (different colors).

After working on the development of the processes in the representation tool, three methods will be used to triangulate the effectiveness and usefulness of the tool itself. The first would be interpretive on my part as the researcher. The second is on the part of the immersive case study, using a follow-up

interview of the participants, preferably colleagues who have worked in firms. The third is the member checking or Delphi stage. The more preferable of the two would be the Delphi, allowing for a group of 8-12 experts to use the representation tool for a number of different design cases. They would sort through the steps necessary to design the vegetated systems according to color theory. Afterwards questions and information gathered at the meeting would be used to inform another iteration of the prototype representational tool.

What is more probable is the development of a studio with 8-12 students who would use the tool as a part of their design work over the semester. This project may involve either the carport vegetated wall or a thesis-like studio, depending on the studio year taught. The students would maintain a journal about working with the tool as they work through a design prompt related to the concept of vegetated assemblies. Then at the end of the semester the work would be presented and final thoughts on the prototype design tool would be recorded. The journals would be turned in after grades were established to not negatively impact their performance and critical analysis of the prototype tool out of concern for their personal assessment for the studio. As with the Delphi, afterwards questions and information gathered at the meeting would be used to inform another iteration of the prototype representational tool.

Figure 4: Carport under construction in 2014

Validating Findings/Further Study

By using some of the characteristics outlined by the photographic studies and simulation reproductions, the decisions made in the electric car garage would validate some of the tenets of color theory as applied to vegetated walls and provide a base for further study. Continued monitoring of the car

charging garage structure after completion will determine the survivability of the plants and efficacy of design decisions. The computer simulations of possible designs would also show the potential of the characteristics amassed in the study to be used in architecture.

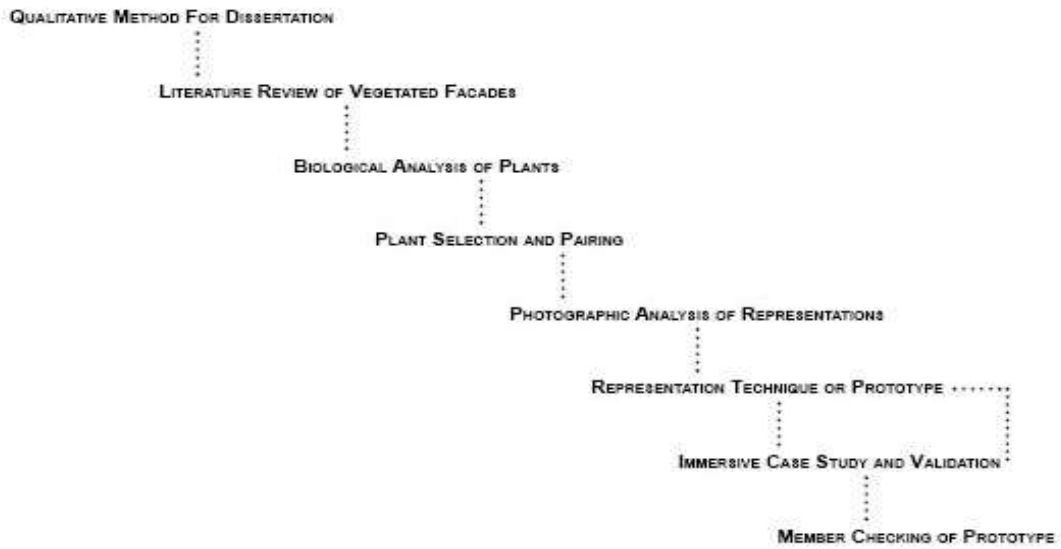

Figure 5: Simplified overview of methodology, full diagram in Chapter 3

The study could be expanded by enlarging the geographic areas from where plants are chosen. Then, after a necessary number of examples and desirable design characteristics are compiled, a decision support structure (DSS) could be developed to aid in the aesthetic qualities from which an architect or designer could choose. This system would not design vegetated assemblies or architecture for the designer. The system would provide a base of knowledge that could be drawn from and then utilized, streamlining the process and incorporating color theory more actively into vegetated assemblies earlier in the design phases.

Anticipated Ethical Issues

Ethical Issues could arise if the study reveals either through the design process, or through the monitoring of the electric car structure, that certain types of plants or products do not perform as specified. Moreover, if certain species of plants, proprietary or not, perform better than others, the study cannot inadvertently place product placements or unfair advertising for or against them. The

characteristics amassed in the electric car garage project and field studies must rely on facts with critical thinking applied. The success or choice of certain plant species could be detrimental as some companies could have a vested interest in the use of vegetated building assemblies as an aesthetic into addition to the primary environmental benefits. Therefore, as a researcher it will be prudent to remain a third party while observing the characteristics and plant biology in vegetated assemblies.

Preliminary Conclusions and Significance

The application of color in the design of vegetated assemblies provides a unique opportunity to merge nature with architecture directly. Predictive modeling and prototype rendering as this study suggests will allow for more standardization in the design process while allowing for more accurate representations of vegetated facades. Architecture exists as an expression of man's engagement with the surrounding environment, as an interface between the individual and nature.

Architecture should be responsive to the conditions on the site and design should allow for accurate representation. Therefore the application of research will create a more accurate projection of vegetated facades for the client. A designer cannot take the phenomena of nature on only faith or fact, relying solely on the literature. The designer must synthesize experience with the problem at hand. Thinking is necessary to a more complete understanding of a given intervention; therefore a small study should be conducted to show the whole process of creating the prototype representational tool. This study would start from selecting plants with experience, to testing growth patterns, then mimicking these patterns and colors within the context of the prototype tool and color theory.

Preliminary Conclusions and Significance: Vegetated Assemblies

When vegetated assemblies are used as architectural systems, it is important to consider over time, the interaction of plants with each other spatially and chromatically and how we as designers begin to use that aesthetic. For vegetated assemblies, this manifests as the characteristics of plant biology coupled with color theory influence the designed space. This study looks for the specific regional expression in an Appalachian Mountain climate based on useful and local flora in these vegetated

architectural walls and how designers may begin to simulate the design of walls for aesthetics using computer based representation.

The active and passive (reflective) modification of light yields colors. The question of color theory in relation to plant biology in vegetated assemblies is not proven or disproven, but observed to gain information on potential characteristics. Therefore, the study considers and examines these as architectural elements of the visible world in order to purposefully design aesthetically pleasing objects. This is what designers can give to the users by taking into account and carefully crafting the stimuli in a space.

Figure 6: Blue/Orange Watercolor

Light is the progenitor for colors. Using light and the color theory that arises from its interactions with the environment, the design of vegetated assemblies can be considered for both aesthetics and performance. Color is on a spectrum and is highly influenced by other colors in proximity. Color is always determined by its context and source light. Due to the relative nature of color, the language around color is also personalized, in that the perception of color is dependent on the individual experience. While color is at times variable, the base tenets of color theory provide a common base from which color can be evaluated. Color is not a binary situation and by definition color is placed on a spectrum and should be evaluated on a continuum of conditions in physical, artistic, and biotic contexts.

From these base tenets, color theory can be applied to the physical world. In this study, the electric car garage project and field studies can reaffirm the colors and pairings found in color theory and begin to understand their application in architecture. The built environment creates an atmosphere for the user to experience the space. Thus, while individual colors can be dependent on the perception of the user, the individual experience of the user is based in the applied tenets of color theory. This self-reflexive experience allows the designer to both influence the space through design in color theory and later be influenced by the constructed space along with other users.

Nature and its application can provide the inspiration for man-made intervention in vegetated assemblies. The ability to bring a natural setting into the urban environment cannot be underestimated.

As explained previously, bringing vegetated walls and façades into harsh urban settings produces positive effects, both intrinsic and performance based. They decrease air pollution, thermal loads, stormwater runoff, and increase the user's quality of life. This increase in the quality of life can be found in the biophilia theory proposed by Edward O. Wilson, in which humans feel an innate connection with nature. This connection back to nature provides context and an impetus for the use of color theory, taking a somewhat abstract theory and grounding it in the natural environment.

However it is important to perform an analysis of observations made after the amassing of characteristics and desirable qualities. This amassing is not to form a catalog prescribing architecture. It is to show qualities that are found in architecture, color theory and nature and then allow the designer to apply concepts, not prescribed solutions. Architecture is not a problem to be solved, but a process of inquiry over much iteration. These iterations allow for the process of exploration that architects need to refine their architecture. This iterative process has ideation to representation to iteration, with many revisions and circular evaluation along the way. As such, a combination of both theory and practice solidifies assertions made from the study in the form of a built construct.

Figure 7: Diagram about ideation, representation and iteration. The prior theme maps from the definition of terms fit into the diagram at all three stages, with the main focus on informing the representation of vegetated assemblies.

These characteristics of color theory and plant biology have implications for the design process. If these considerations are implemented earlier in the design, vegetated assemblies can be a critical facet of the design. The varying climates due to geographic regions and different building standards could change the effectiveness or necessity of some design decisions for better or worse. As mentioned before, a design should be reflective of the surrounding environment and site conditions. If the site and climate is ignored, then the final intervention has not reached its full potential. While color theory as applied to vegetated assemblies is important, these assemblies must gain further acceptance and then be validated

by construction and repeated methods in order for designers to gain practical experience, and not simply theoretical knowledge. From this initial understanding of the vegetated assemblies, designers will then be able to experiment and improve the quality of systems.

However, the actual aesthetic of the vegetated assemblies and the reaction to the building conditions and climate is not completely predictable, nor should it be. This allows the process of ideation, representation and iteration to inform the design of the ‘wicked problems’ in design. A decision support structure (DSS) such as the accumulation of analyzed design explorations and field study conditions can show designers a beginning to start from, but not an answer. Architecture and design is not a problem to be solved, but a process to be explored.

2

Literature Review: A Basis for inquiry

Color Theory as it Relates to Vegetated Walls

Historic Color Systems

We should begin with how color as a theory began, looking at how the theory developed. Much of this synopsis of the history of color circles and their associated theories was compiled by Faber Birren, who was an industrial color consultant and recognized as an expert in that field. The history of color goes back to antiquity. Intellectuals such as Pythagoras, Plato, Aristotle, and da Vinci all contemplated the nature of color, but it was not until Sir Isaac Newton and Geothe developed color theory that a systematic attempt was made to characterize color and spectrum (Birren, 1969; Holtzschue, 2006). Geothe devised his color theory to disprove Newton, but fundamentally agreed with the totality of color in a color circle (Renner, 1965). Later, J. C. Le Blon uncovered the primary colors of red, yellow and blue. In 1766 a English engraver, Morris Harris made the first full hue color chart in *The Natural System of Colors* from primitive, mediate and compound or tertiary colors (Birren, 1969).

Johann Wolfgang von Geothe believed that yellow and blue were primary as did Aristotle. Geothe believed that, "… yellow came from lightness and blue out of darkness. All other colors, including red, were blends of them" (Birren, 1969). Geothe and his contemporary Phillipp Otto Runge placed color on a color circle and triangle or pyramid (Arnheim, 1974; Birren, 1969). M. E. Chevreul featured the red, yellow, and blue theory in Impressionism and Neo-Impressionism schools of painting. In America, Louis Prang, Milton Bradley, Arthur Pope, and Herbert Ives who were prominent educators, made the red, blue and yellow theory part of American color and art education (Birren, 1969). Other types of color circles have been developed, however the red, blue and yellow has been favored the most.

In 1826, the German scientist Helmholtz expounded upon the work of Thomas Young's theory of color vision to make a red, green and blue (violet) color system (Arnheim, 1974; Birren, 1969; Holtzschue, 2006). In 1923 Michel Jacobs, a painter and teacher set a theory of principles of color harmony based on red, green, and violet primaries similarly to Helmholtz and von Bezold. Finally the color circle of Albert H. Munsell also traces back to Helmholtz (Birren, 1969). The work of Bloomer, Falk, and Küppers in the 1970s and 1980s continued to evaluate color theory. Then work of Steven Bleicher in 2005 continued this tradition of refining color theory and its response to increasing technology (Bleicher, 2005). The constant

is that while the color circles and color classification vary, they are all based on the same layout of characteristics, which will be defined later in the section.

So why are there so many different types of color circles? Birren explains that, “there are three sets of primary colors and therefore three good reasons for different types of color circles” (Birren, 1969). He explains that pigment primaries are additive, that red, yellow and blue will form other hues. Light primaries are subtractive in which red and blue can form yellow. Vision primaries are medial formed from red, yellow, green, and blue in which all of them mixed together will form grey (Birren, 1969). Later in this study the concept of mixing colors and methods of representation will be discussed further.

Biophilia and Nature as a Model: Ingrained Images and Color

Why do we feel connected to this transplanting of nature into architecture as described by Ulrich (1984)? Juhani Pallasmaa, Finnish architect and academic, explains that beauty is rooted in human life. The human experience of an individual is based in that individual’s biological past. Pallasmaa states, “Real architecture can only affect our soul if it can touch the stratum of forgotten memories and feelings,” (Reisner & Watson, 2010). He terms this category of image a “primal image”, which awakens the most ancient memories of the forgotten past (Pallasmaa, 2001; Reisner & Watson, 2010). If we believe that people have a connection to a forgotten past and innately seek aesthetic images that invoke those memories, then we as people, have a fundamental connection with nature. When we engage this world, we engage nature and we must be able to trust our gut, our instincts without understanding every aspect of the experience.

This innate connection with nature is also supported by the work of Edward O. Wilson, biologist and researcher at Harvard University. Wilson terms this innate connection to nature and the natural world as biophilia (Kellert & Wilson, 1993). Just as there is not one image that invokes our forgotten past, there is not one emotion that is drawn upon in the web of conditions that make up biophilia. In nature and people there is a spectrum of images that create a range of emotional responses. As such there is a range of plants that respond and adapt to different stimuli in the natural environment. These different plants, based on their inherent aesthetic or beauty created by specific environments, will invoke different emotions from the connection to nature in our forgotten past. Combining these two concepts of a primal

image, from an ancient past, and biophilia, the predisposition to enjoy natural landscapes, we develop a notion for why nature often serves as a model in design.

Biomimicry studies nature in in its natural environment to gain information and then create artificial reproductions for humans. This method is used in scientific research to discover the phenomena of a system and its mechanisms in relation to its inherent nature.

Synthetic biology, most notably the work in recombinant DNA techniques by Stanley Cohen and Herbert Boyer in 1996, the discovery of restriction enzymes by Werner Arber, Daniel Nathans, and Hamilton O. Smith in 1978, and the invention of polymerase chain reaction techniques have drastically changed medicine and biology and humanity's understanding of our own physical being. Furthermore the combination of the work of Tom Knight at the Massachusetts institute of Technology (MIT) with 'BioBricks' allowed for the construction of systems using biological components and the work of Roger Brent, Robert Carlson, Drew Endy and Adam Arkin at the University of California with more engineering specific means brought synthetic biology forward. This with biotechnology will serve to inform design tremendously in the future. We [humanity] learn first through mimicry and then develop an individual interpretation. This occurs often in design and in life in general (Ternaux, Ternaux, Ternaux, & MatériO (Firm), 2012). Living walls are the novel creating productions, the mimicry of nature, in an urban setting in an effort to re-enliven a space. Designers take the qualities of a natural setting and attempt to recreate an urban or constructed space in its image.

Viewing Color: The Eye and Mind

As with color circles and the numerous ways to categorize color, it is understandable that color theory in reference to architecture and vegetated assemblies should be phenomenological, and that our observation of phenomena is based upon our perception of space and objects. Eugene Raskin, author of *Architecturally Speaking*, explains that: "to treat architecture without considering the psychological and physiological characteristics of those by whom and for whom it is created makes no more sense than a discussion of the Bach fugues between two baboons…" (1966). This is to say that architecture when viewed by the individual is a relative concept; so is color theory when viewed through an eye. We, as designers must approach architecture and subsequently aesthetics and color theory considering our own

preconceived notions and abilities. Therefore, in this study color theory is considered in psychological and physiological terms by being limited to the perceivable world of the individual's or researcher's eye; and in the physical theory of color that looks at the manifestation of color by the eye, respectively.

Another important thing to consider is that when an image is viewed, it is placed on the individual's retina. As the individual interacts with an object or architecture the eye must interpret the information it gathers continuously (Raskin, 1966). The image is seen by the eye, and perceived by the brain (Bloomer, 1976). This is to say that when we observe a phenomenon, it is filtered by our own physical and mental characteristics. As designers we cannot have an exact representation of the space: instead of reproducing an image as a camera, we create moods and representations. The process of design is inherently biased towards a visual process. Though the process is dominated by the visual, other senses are still observed. It is vitally important not to reduce vision, color, or representation to simply a picture. Furthermore, the objective of this study is not to completely predict or validate an individual's perception of the space, but influence how the designer goes about representing the space.

If we continue to evaluate phenomenology in the context of how to engage vegetated assemblies in relation to color theory, French philosopher Merleau-Ponty in his book *Phenomenology of Perception* separates and distinguishes his philosophy from the mindset of Descartes and Kant. Merleau-Ponty, in reference to Kant and Descartes, says, "I could not apprehend anything as existing, unless I, first of all, experience myself as existing in the act of apprehending it" (Merleau-Ponty & Landes, 2011). However, Merleau-Ponty contends that in the observation of phenomena, perception and judgment are not equivalent. Finally, Merleau-Ponty suggests that the surroundings, the world outside the observer, become imprinted upon the observer through perception. This will become important during the study as we need to observe our surroundings and objects based on our previous experiences that have been imprinted upon us from our past perception and experiences of the world.

Our own interactions with a phenomenon influence our observations, and the concept of color theory in relation to vegetated walls takes its roots in Goethe's method of interacting with and perceiving phenomena. Laws of nature, such as light and color will always exist, but an organ such as the eye must be present to manifest the physical condition. The eye does not cause light and color to occur, but allows it to appear to us. Thus the physiological theory of color proposed by Goethe is different from the laws of

optics proposed by Newton (Goethe, 1971; Steiner et al., 2000). Geothe also inspired his student, Schopenhauer, who attempted to define the role of the retina in vision and color in terms of the subjective and proposed complementary colors due to afterimages. (Arnheim, 1974). In this vein, the characteristics and conditions of plants in vegetated walls will be studied by the conditions observed by the eye. The study looks at what and how color phenomena arise, and how these phenomena are perceived.

The study will be conducted through the observations from the eyes. So how will this affect the observations and perception of the study? According to David Falk from the University of Maryland, there is a delay to the eye when introduced to new phenomena. Our eye then responds to these conditions to give the individual a representation of the space after a lapse in time (Falk, Brill, & Stork, 1986). Light can create space with depth and shadows, but the way in which we interact with light and therefore color in our visual perception stems from, but is not limited to, brightness, form, texture, depth, transparency, motion, and size; that a human eye can distinguish one object from another, recognize and interpret scenes (Bloomer, 1976; Falk et al., 1986). These delays and residual images on the eye play a role in how an individual perceives space and color. The information collected by the eye creates a representation of the space in the mind. The results become the way that we, as designers and individuals, perceive the visible world.

Before we talk specifically about color in vegetated walls, there are some characteristics of the eye that are important to understand. Foremost, the brain processes collected information while emphasizing changes in the surrounding space and sorts this information. Falk explains that neighboring regions of the eye can inhibit each other. This effect of lateral inhibition can be explained with the case of a white square appearing brighter on a black background and a black square appearing darker on a white background. He further suggests that in the processing of visual information within the retina, which decreases the effects of uniform changes in illumination, enhances the effects of edges called the Crail-O'Brien illusion (Falk et al., 1986). Therefore, when constructing and designing vegetated assemblies, it is not only important to consider the edge as a design intervention, but also from the eye's need to differentiate space. The edge not only can define the space, but also the character of the internal field of vegetation and its color.

Afterimages will also augment the perceived color of the vegetated assembly. Falk describes two types of afterimages that will affect the perceived space: negative and positive afterimages. First, prolonged stimulation to a set of conditions desensitizes the eye and leaves a negative afterimage. Second, an intense light will overstimulate the eye and leave a positive afterimage (Bloomer, 1976; Falk et al., 1986). An example of an afterimage as related to color is found in the polarized tint of ski goggles. For example if the tint is an orange color, when the goggles are removed a bluish hue remains for a short period of time. The effects of afterimages could change the appearance of certain types of plants based on proximity and intensity. Just like the goggles, if you look at the color of a plant long enough, this can affect the appearance of nearby plants, as your eye may adjust to the color of one plant, augmenting the other.

Some Examples of Color and Perception in Design

When an individual interacts or engages with a vegetated assembly, a specific space and depth influences the individual's perception of that space. Architect Steven Holl, explains the concept of parallax which helps the individual understand space. Holl describes parallax as "the change in the arrangement of surfaces that define space as a result of the change in the position of the viewer" (Holl, 2000). We as individuals rely heavily on parallax as it creates depth cues in order to understand space (Bloomer, 1976). However, for a two dimensional representation, we rely on ambiguous depth cues of apparent size, perspective, variations of light, shadow, color, and sharpness to define space (Falk et al., 1986). This will become important in representing the designed space using computer simulation of vegetated assemblies later in the study.

With experience, designers can use patterns on two dimensional media to imply overall depth using overlays and superposition. Based on the writings and studies of Josef Albers, other considerations such as color interacting with other colors, the interdependence of color with form and placement, the quantity of color, the quality of each color, and boundary conditions, also need to be addressed (Albers, 2013). Both Albers, and Arnheim, a perceptual psychologist, describe the concept of using overlapping figures to imply depth (Albers, 2013; Arnheim, 1974). In superposition there is a specific case called

transparency. Below are two examples of superposition from a personal watercolor study about Albers, which will be taken into more depth later with a review of his book: *Interaction of Color*.

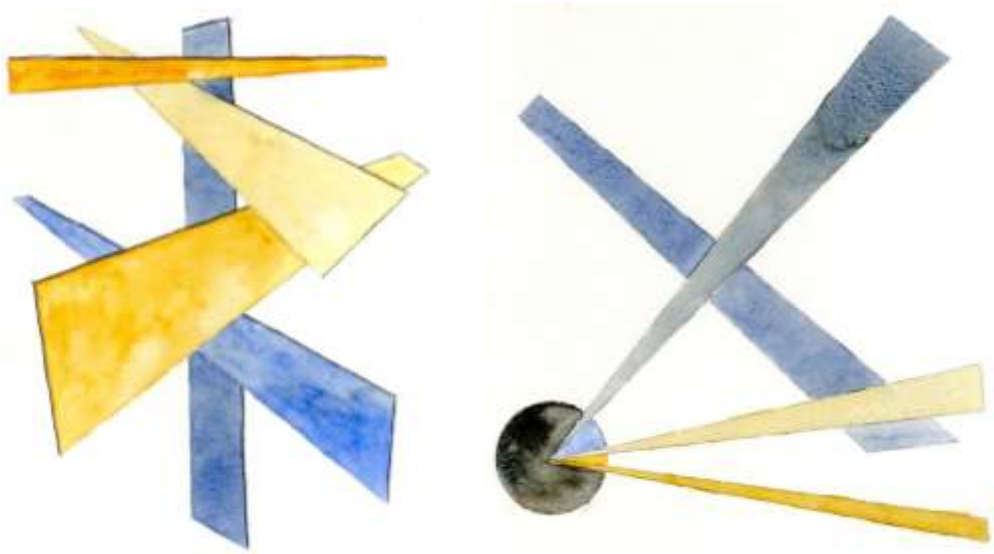

Figure 8: Two watercolor studies of superposition using the compliments of orange and blue

There are two types of transparency, first when light can physically pass through; the other is perceptual transparency through media and methods of which Albers has many examples in *Interaction of Color*. The illusion of transparency is created after looking at the fields of color long enough. The closer the middle field is to the true mixture of the two other colors, the more this effect is seen. This kind of illusion also begin to expose a type of mixing called partitive mixing, where adjacent color can begin to mix together.

Albers was one of the most influential teachers and artists of the twentieth century from the Bauhaus tradition and his text is one of the most important works on color and its interaction with surrounding space. These themes of perceiving depth, texture, and qualities of space in Albers' work, with the characteristics of color will be critical to representing and understanding not only the space created, but the vegetated assemblies as well.

Taking a step back, a line is the simplest form of divided, or with multiple lines, enclosed space. A line delineates, and creates an edge. Lines also relate to the context of the medium, its range and extent, of the two-dimensional frame in which they rest. If we consider that the eye is invariably attracted to an edge condition, then lines become critical in design and color. Piet Mondrian, a Bauhaus painter and

educator attempted to reject references to physical space, but the distinction between objects and the space around them remained (Arnheim, 1974). In the principle of interposition that Albers and Klee explored, using fields (Albers) and lines (Klee) depths can be created or rejected based on position. This concept of proximity and position to create or deny space and depth will be critical to understanding color and its resulting effects. Lines can also create volume when transferred into the third dimension (Hogarth, 1955). This idea of lines creating a volume was also explored by Moholy-Nagy in structural and allied constructions (Arnheim, 1974). Klee also looked at how lines could enclose space, making a distinction between internal and external spaces. In some of his paintings, two examples are: *The Draughtsman at the Window* and *My Room*, Klee would use windows to show a way of looking at an external, brightly lit world, from a relatively dim interior world. (Aichele, 2006).

Arnheim explains that a circle could be perceived as an object line; however the enclosed space could be perceived as a solid entity such as a disk, and the surrounding field more loose and flowing. This idea of an object and an area contained by a frame introduce the concept of figure-ground. The disk becomes the figure to the observer and the space around it becomes the ground (examples shown below) (Arnheim, 1974). These lines can be used in designing the field density proportions of a vegetated assembly as well as how the edge conditions of color are resolved.

Figure 9: Figure-Ground examples: (left to right: circle, line, rhombus, square)

The figures above show different aspects of figure and ground. The first set of images is a circle that encloses space as compared the singular line to its right. The enclosed space of the circle makes and figure and the white space around the figure is the ground, thus the concept of figure-ground. The second set of images is a rhombus and a square. Both the rhombus and square enclose space and create the figure-ground concept, but the rhombus angles back in the field, creating a sense a depth, while the square does not. Individuals can use depth cues as shown by Albers and Arnheim to define a space conceptually as in figure 11.

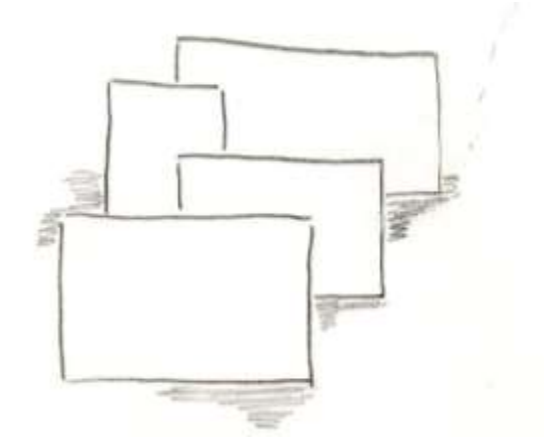

Figure 10: Overlapping planes

So how are colors described for their depth and qualities? We could define color solely by wavelength; for example the color blue is between 455 and 485 nm (nanometers), which is a range of wavelengths and not a single band. A single band or wavelength of color is termed monochromatic light. However defining a color by something that is not perceivable to the eye is not a viable descriptor. Over time, three dimensions of color have been used to define color. We can define color by hue, its main color which distinguishes it from one spectral color to another. We can define color by saturation, its purity of color or how much of the color is near the dominant wavelength. We can define color by lightness, its percentage of incident light reflected from the surface. These three characteristics: hue, saturation, and lightness, that define color to the eye can be arranged on what is called a color tree (Falk et al., 1986; Munsell, 1913). These groups can also be defined as hue, saturation, and brightness (Arnheim, 1974); hue, intensity, and value (Bloomer, 1976) or hue, value and chroma (Munsell, 1913). Even while these general characterizations are of the same concepts in color, language still cannot completely describe color and this range of naming color responds to the variation in perceivable color.

While we cannot determine how an individual will interact with a space or color as explained previously, we do have the ability to suggest a perception of a space. Using the combination of historical precedents as well as design experience, architecture and by extension vegetated assemblies, can begin to imprint the individuals around them by maintaining a particular atmosphere and innate connection to nature. These resulting atmospheric qualities are derived from the perception, intentions, and experience of the designer's hand.

The space and shape that a design creates can be a means of identification that is more consistent in the face of environmental changes than color (Arnheim, 1974). However, the possibilities of combining shape and color in design, be it a vegetated assembly or architecture in general, is worth noting. Luis Barragàn, architect and the 1980 Pritzker Prize laureate, speaks not only of beauty (aesthetics) and color, but also of gardens. These motifs, these themes will be critical to understanding

how designers can use space, color, and light to enhance a vegetated wall or assembly. Armando Chàvez Cervantes, the chairman of The Fundación de Arquitectura Tapatía Luis Barragàn, FATLB describes Barragan's view of architecture, "To see and make with what exists, with an open, revivified vision, in the aim of revealing to us a new universe, his universe, enveloped by magic, mystery, enchantment, light and color." (Alfaro, Garza Usabiaga, Palomar Verea, & Barragán, 2011). Barragàn was a master of combining a connection to nature and color with a sense of place.

The characteristics of color reviewed in the literature (hue, saturation, and lightness) can be quantified and scaled, but solely quantifying color does not relate to an architect attempting to represent a space in a two or three dimensional manner.

For an architect, the characteristics of pigments, medium, paper, and methods combine to give characteristics of color and create aesthetics of design. Thus, our plants (pigments), our assembly (medium), our space (paper), and our design (methods) must be in relation to each other and thought of in a cohesive whole. Although color theory can be the focus of the study, many other aspects such as contrast, assimilation, a sense of place, a sense of beauty, and perception must be applied and allowed to mix and complement each other.

Figure 11: Pigment mixtures of blue, orange, and black

Color Mixing and Harmony in the Representation

There should be a dynamic view of the space, not a static view in our minds. The space that we design changes over the years, with the seasons, the weather, the number of people present, the lighting conditions, the form of the space itself, and much more. The subsequent representations created by the designer need to show a way of experiencing the sense of place proposed by the representation, and the

possible built construct. The designer should represent a desired experience or mood to the space. The representation should be an approximation of the desired physical stimulation combined with a mental response, filtered by the memories and innate nature of the individual. The individual creates a personal phenomenon of interacting with architecture, one that we can never completely know, but can attempt to represent.

Utilizing all of these ideas of vegetated walls, knowing their research and historical context, and evaluating these walls based on color theory, we now can re-imagine a designed space. We, as humans, perceive and attempt to generate an image of balance, or harmony. Referring back to biophilia described by Edward O. Wlison, and the “primal image” described by Pallasmaa, then we can begin to piece together a desire for harmony and balance that is also found in nature.

Simulation and representation are the two main components of how a vegetated assembly would be described or visualized before the actual construction and implementation. The architect should seek a composition that is in balance, especially in reference to color theory. When simulating a space, the production of the representation and color balancing play a critical role in the final result. You simply cannot mix plants by color the same way a printer makes colors. There are differences between the three dimensional world of the built environment and the two-dimensional world of graphic representation which make them not directly translatable. However, representation can and does inform the final construct. This study will look specifically at how predictive simulation models for the aesthetic appearance of vegetated walls can be used in the design process and how the representations relate to the built form and aesthetic qualities.

As Arnheim explains, colors can be determined by three different dimensions: hue, brightness, and saturation (Arnheim, 1974). These three qualities show up in color pyramids by J.H. Lambert in 1772 and in color graphics of Philipp Otto Runge in 1810. What is derived from the work is the inter-related nature of hues. Arnheim contends that this type of color harmony is incomplete, only focusing on connection of the hues, and neglects separations of color. Ruskin, as described by Arnheim, and others find that this is mainly found in the instability of colors that hot and cold hues remain relative to the new colors placed on the canvas, and with each stroke new relations are established, that hues and colors are relational and interact (Arnheim, 1974; Birren, 1969; Holtzschue, 2006; Renner, 1965). Furthermore

Albers describes this in his work in the *Interaction of Color* (Albers, 2013; Arnheim, 1974). Itten also describes color harmony as the interaction of two or more colors (Holtzschue, 2006). He states that "the concept of color harmony should be removed from the realm of subjective attitude into that of objective principle" (Holtzschue, 2006; Itten, 1961). This is countered by Albers who states, "What counts here— first and last— is not so-called knowledge, but vision—seeing." (Albers, 2013; Holtzschue, 2006). Geothe found that harmony was present when the totality of color was present in a composition (Goethe, 1971; Renner, 1965). Renner, a German educator and designer, viewed a harmony as a combination of a few main colors, and each color should be in relation as a subordinate or coordinated color (1965). While art will always be subjective in nature, it is interesting to see the interpretations of color harmony are dependent on the artist and their perceived method of knowing and philosophical stance.

The color studies and philosophies of color harmony differ by the artist. Albers viewed cold and warm colors to coincide with dark and light. Itten saw red-orange +blue-green as temperature opposites, that red was warm or sunny and blue was cold or shady. Kandinsky saw colors as shapes that yellow was a triangle, blue was a circle, red was a square (Arnheim, 1974). This concept of using multiple words in language to describe similar hues via different thought processes is inherent to color, that an image or hue is meant to be seen and represented, that words cannot describe and image in its entirety.

Birren speaks of the color harmonies developed by Chevreul in 1839. These six color harmonies can be summarized as the harmonies of adjacent colors, of opposite colors, of spilt compliments, of triads, of a dominant tint (Birren, 1969). This method of color harmony addresses the incomplete nature described by Arnheim of only viewing a similar set of hue as a complete composition. What Arnheim discussed is termed the harmony of adjacent colors by Birren and Chevreul, for example yellow, yellow-orange, and orange. Then the shortcomings noted by Arnheim are addressed: the harmony of opposite colors as in blue and orange, of split complements as in orange with blue-green or orange with blue-violet, of triads as in red, yellow and blue, and of a dominant tint such as a light source washing colors with a light orange from an incandescent bulb (Birren, 1969). Birren also explains that the eye looks for simple and clear divisions of color. Perhaps this can be found in the ingrained human eye's tendency to focus on edges and color divisions. Compositions that are vague or blurred are disturbing, and the mind desires order and neatness. The eye will notice dis-harmony and will be disturbed until balance and

proportion are once again evident (Birren, 1961). These experiences are characterized by the absence of gaps in the color harmonies (Holtzschue, 2006).

Holtzschue, after explaining color harmony in depth, suggests four near-universal observations about color harmony (2006):

> *The complementary relationship between hues is a strong basis for harmony, but it is not the only basis. Any hues used together can be harmonious. Even intervals between colors are harmonious. Even intervals are pleasing whether they exist between colors of different hue, different value, different saturation, or any combination of these qualities. Color compositions are most harmonious when the level of saturation is relatively constant. Complex compositions, with a great many colors, tend to be most successful when there is a dominant family of analogous hues that is supported by lesser areas of their compliments.*

This series of observations combined with the harmonies developed by Chevreul and distilled by Birren, makes a solid foundation for the study of color and color theory.

Two Types of Color Mixing: Light and Pigment

Since only in specific cases are representations monochromatic, mixing color and understanding the harmony or contrast in color is essential. When mixing specific color hues in light, they should give white (complementary pigments in paint will yield a grey), and when placed in proximity to each other these color pairs enhance each other, becoming complementary colors. Colors can be grouped to be pleasing to the eye, or to clash in order to draw attention. Architects, such as Barragan and Legorreta use color to their advantage in order to make a composition of colors like Barragan (Alfaro et al., 2011) or for example, Legorreta uses color as a symbol of emotion as a premise of the world around the individual, and specific to the cultural and geographic location (Legorreta Vilchis, Attoe, Brisker, & Box, 1990; Mutlow, 1997). These two architects certainly use other motifs in their architecture, and color serves to enhance their stance in architecture.

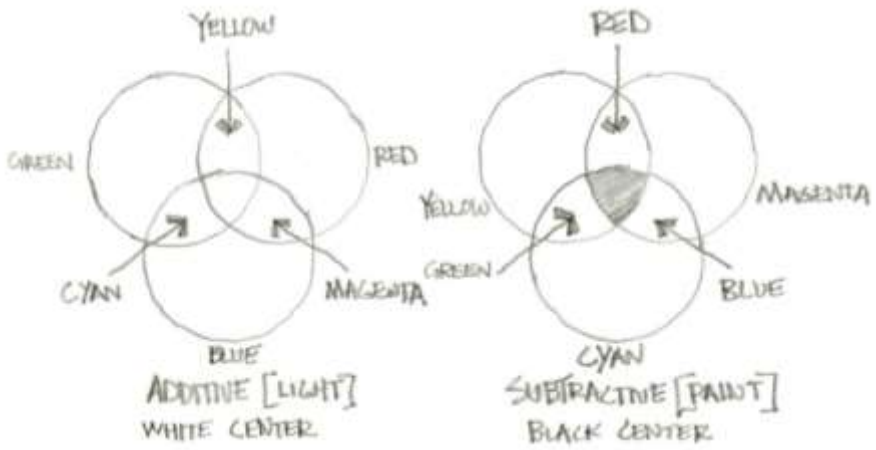

Figure 12: Color Mixing RGB (additive) and CMYK (subtractive)

Diving deeper into the concept of complementary colors, two colors that mix together and give white are generative complementary colors; however, colors that appear to be complementary to the eye are called fundamental complementary colors (Arnheim, 1974; Birren, 1969; Falk et al., 1986). The generative primary colors, not strictly based on red, green, blue (additive primary colors), are: blue with yellow, cyan with red, and magenta with green. These additive colors combine to make a new color, while subtractive colors cancel out wavelengths to make a new color. The traditional pairings found in art and art pigments, based on red, blue, and yellow are: blue with orange, green with red, and yellow with purple.

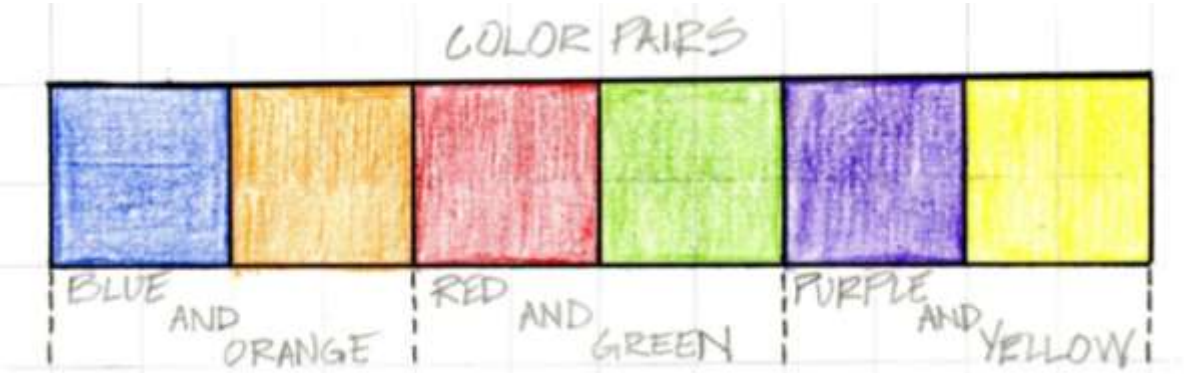

Figure 13: Traditional Color Pairings

Furthermore, using the color circle we can generate complements (Birren, 1969). For example blue and yellow give green, the complement of red and in this example green is a secondary color. (Falk et al., 1986). There are different sets of pairings based on the interpretation of color and its medium. Color can be viewed from a physical, artistic, or biotic view.

If we use these three methods of interacting with color, physical is of physics or the scientific measuring of light and its properties, artistic is of the arts or the application of color in physical representations, and biotic is of physiology or the view of the conditions by the eye. However, this does not mean that one particular method of viewing color is dominant, nor does this mean that these methods are mutually exclusive. When attempting to understand color for its entire worth, it is important to review color for the combination of each of these methods. Color is not a binary, it is a spectrum and it should be viewed as a continuum, thus its methods of viewing should be treated as a spectrum.

The art of design is also a process, and a spectrum of work that begins with the inception of the idea, continues to the graphic representation, and manifests as the built construct. During the design process other questions will present themselves, but this study will focus on the kind of harmony that is designed into the project by using color. The color that is seen in the mind is different from the color viewed in its physical, artistic, or biotic manner. This is not a hurdle to overcome, but a dynamic to be embraced and understood. The color palette for the design needs to be considered along with the kind of color mixing that will occur in each method of viewing to maintain a harmony at all stages of the design. When thinking about colored mixing, there is additive and subtractive mixing (Albers, 2013). In additive mixing, the intensities of wavelengths combine to make another color and include: simple addition, partitive mixing, and color mixing. The first kind of additive mixing is simple addition. Simple addition is when colored light overlaps and combines wavelengths to make a new color.

Partitive mixing is when the eye combines sources of colored light in proximity together. Color mixing with positive afterimages is when the eye adjusts to a set of prior conditions and then a new condition is imposed rapidly. The time it takes for the eye to adjust can result in color mixing. Subtractive mixing occurs when combining filters or dyes to admit some wavelengths and block others. However, subtractive mixing will depend on the light source and its distribution of light (Falk et al., 1986). Furthermore, a particular scene will look different under different light at different times of day.

If this next image is viewed on a digital screen it will behave as light in partitive mixing, however if the copy is printed out it will behave light color pigments, explained below the figure. In the portion of the image below, the lines show a generalized field of a color green if viewed long enough as the blue begins to influence the lighter yellow, making a light green mixture.

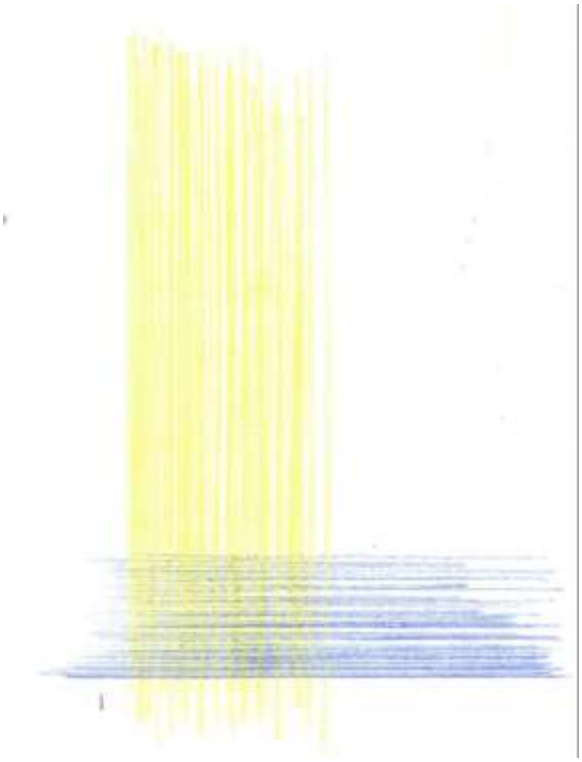

Figure 14: Partitive Mixing

If this image is printed out, colored pigments behave in a different manner and the partitive mixing is almost impossible to achieve. The colored pigments mixing first begins as a subtractive process, that is concluded additively when seen by the eyes (Falk et al., 1986). For example, a pigment will be mixed and applied to the media.

If two artistic pigment colors (blue, yellow) are mixed they additively combined to make a new color (Birren, 1969; Falk et al., 1986). When light strikes the pigment on the page light travels into the pigment, and all light other than what is reflected is absorbed and subtracted out. Light is also then reflected off of the media behind the ink, back through the pigment again. The light from the pigment and the light from the page are then additively combined in the eye. If designs are done digitally, colors in printers can be cyan, magenta, yellow, black (CMYK) or red green blue black (RGB), which is called four color printing. (Falk et al., 1986). These different types of mixing light and color are a result of combining different forms of pigments, medium, paper, and methods combine to give characteristics of color and viewing them from physic, artistic, and biotic methods of observing light. When designing with color theory in mind, the color balance of the computer and the program (such as vectorworks, revit, or maya) used to render the space is also an important consideration.

Watercolor Study of Josef Albers' *Interaction of Color* This study will be conducted to see the interaction of light and pigments. The way watercolor paints and paintings combines both the interaction of additive mixing in mixing the pigments, but also the subtractive mixing of light through the layers of the watercolor painting. This study will be conducted in conjunction with the analysis of vegetated assemblies in regards to color theory. The study was brought out of a larger set of interventions and studies into color theory and the interaction of color that was conducted by Josef Albers, and will contribute back to those studies of color and design.

The themes of perceiving depth, texture, and qualities of space, with the characteristics of color will be critical to representing and understanding the spatial representation that is drawn. These qualities of color and texture will then later be applied to vegetated assemblies and their representation, which is the main focus of my Master's study. The purpose of this specific study is to help myself and other students who participate in its implementation to determine how theories of design translate into different media, in this instance watercolor instead of colored paper, both in performance and aesthetic quality.

Background of Albers

In order to understand the work of Josef Albers, it is first important to understand his own work as a designer and artist. Albers studied and taught at the Bauhaus until 1933 when the school was closed by the Nazis. Albers then moved to the US and taught first at Black Mountain College, and then became the head of the design program at Yale. When Albers moved to the United States he began to paint more, devoting most of his career from 1949 on to a long series of paintings called Homage to the Square (Morris, 2011). In the work Albers attempted to achieve a totally flat surface using different shades of a family of colors. These colors react with each other, appearing to enlarge, diminish, or change hue when viewed. His 1963 treatise, *Interaction of Colors* is a seminal text and his work greatly influenced artists.

Short Review of *Interaction of Color*

This is not a critique of the work that Albers has provided. That would not prove helpful in learning about color and the ability to utilize or adapt it in design. Instead the review aims at seeing what is offered and then coming to an understanding of the methods and information provided. It is first critical to

understand information and then review it though a particular lens. Then, over time and experience can one begin to understand the subjective and relative nature of color and its interaction.

Albers very quickly explains that, “Color is the most relative medium in art.” (2013). In the work I have seen and in the projects I am currently developing, scores of different colors and hues are used. These colors can be enjoyable to some and then found displeasing by others. It is our own individual interaction with color that determines our appreciation for a composition of color. Only through trial and error have I begun to understand the subjectivity that can be found in contrasting hues and tints of color. These observations and experiences into learning and understanding color result in a phenomenological understanding color and its presence. Therefore color and its theory is something that can be taught, perceived and understood differently by every individual.

Albers then continues by explaining that the name of a color can and does invoke different recollections of the color (2013). This concept is interesting because even in the specific language of the user can the individual find variance in the interpretation of color. These subtle differences in color can sometimes only be found in a particular language and do not translate into other languages. The interpretation of the color can also be based on the person’s remembrance of color visually. However it is important that this difference in the interpretation of color is not negative, but rather an indication of how widely varying the hues and tints of color are and how there are perceived by people. It allows for there to be as many interactions of color as there a people to interact with it; that color is a semi-infinite realm of representation and the resulting interpretation.

He finds that successful studies of color require representation, and therefore are not as often misunderstood (Albers, 2013). He explains that in some instances it is not important to achieve color harmony, but that color is understood. The study of color, even a particular one such as blue, has so many different possibilities that limits have to be placed on the field of colors. Albers conducted this by using studies in separate pairs to show desired effects. Even in the studies based on pairings and families of color, it is difficult to distinguish lighter vs darker in close interval of hues and the interaction that each hue has on adjacent hues. The nearby graphic shows how small increments in hue changes can create a different color over a gradient.

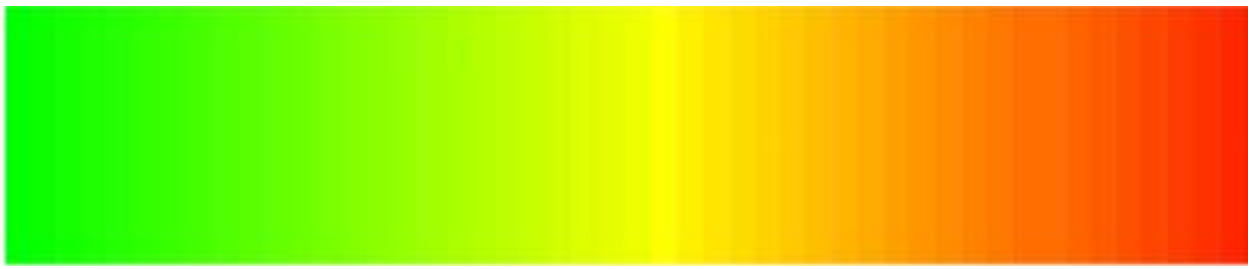

Figure 15: Color spectrum index numbers by multiples of 10 on the color index of complementary colors red and green

Albers describes how the eye interacts with colors as compared to photography. For example, afterimages can be created by the eye with the overlapping of different hues. He explains that the eye has scotopic seeing as well as photopic seeing, and can adjust to low light conditions. He mentions that photography can alter color balances and that it turns darks darker and lights lighter, scarcity of middle range greys (2013). Photography has progressed since his studies and has changed to include digital photography. What is similar across the medium is that the light that enters the lens of the camera is what is recorded and the mechanisms to do so will always alter the color. Just as analog technology changed the resulting image, digital process of changing an image to information also affects the clarity and brilliance of colors. This augmentation of images as compared to the original is less apparent, but still needs to be addressed when copying, printing, and using non-original images.

Since the eye is more complex and flexible than a camera, Albers suggests some methods for how to train the eye to detect and differentiate hues such as gradation studies which use a stepping of grey from white to black, looking for smooth steps in scales (2013). In my own education this method was employed to teach me and my peers how to create, differentiate, and organize different greys. After creating a series of steps in the greyscale, we were asked to create a mosaic of all of the tiles using the contrast in the different levels of grey to develop a language in the grid. It was also asked to try to find the whitest white and the blackest black among the tiles, which was difficult as competing shades either reduced or enhanced the relative darkness or lightness of a particular piece.

After looking at the process of differentiating the varying greys, Albers describes the *idea of trying to identify the* middle color of two different hues (2013). This is very difficult, especially if the pair is a set of complementary colors. The complementary colors of green and red (through yellow) are shown in

figure 9. Trying to find the middle color between green and red would be much more difficult, even with the spectrum, than the middle of a set of greys. Furthermore the spectrum above is only one method in moving from green to red, or the reverse, from red to green.

Then is the idea of how the method of lighting in a space can alter the visible colors that are viewed by the eye. For example you observe a shirt in the store that is a specific hue and then when the shirt is taken outside a different color rendering index, namely the sun, is introduced which alters the color. While this is a specific example of how the change the appearance on one color to two, Albers speaks of how color differences are caused by hue and light. He felt that it is more interesting to make two colors look the same, not one color look different (2013). The experiment that Albers uses is as follows and has been reproduced using a laser printer and resulting color squares from photography. He describes that on a white page three colors of a similar hue can look the same. This is because there is not a reference from the red to compare to except each other. In figure 10, there are three different shades of the same hue. However, chances are if you have printed this out the colors are actually printed the same since many printing devices are not sensitive enough to print a difference. This difference on paper as compared to a computer screen shows how methods of representation and the quality of media can change a result.

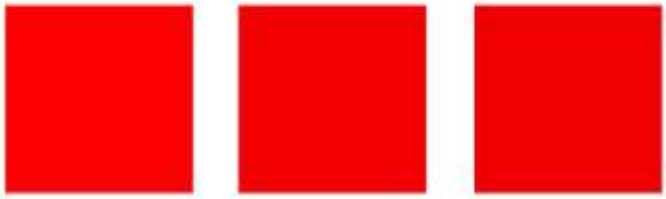

Figure 16: Three hues of red with no background to use as a visual comparison.

Now if these same colors are placed on a hue of same color, then the differences emerge. Next, if same hue of one of the three color samples in used, that color will be absorbed, subtracted into the page. This can reduce, or eliminate, the apparent differences in color. In figure 18, a printer may not distinguish between the different hues of red, solely printing out one rectangle of red. This again shows how the method or representation can change the effect of or a representation. In the electronic format, three

squares appear, each as each hue approaches the hue of the background, which causes the squares to recede.

Figure 17: Three hues of red with a fourth hue background

After doing the exercise above, I noticed the next concept that Albers explains: the idea of simultaneous contrast. This is an afterimage that remains after exposing the eye to a particular color for an extended period of time. For example, red on a white surface yields green and orange yields a blue. He suggests that this is due to the light receptors in the eye, that after staring at a particular primary color for an extended period of time, the eye fatigues, and with a quick adjustment to a more complex secondary or tertiary color (most easily seen with white as I have found after doing the previous exercise) an after image appears. This kind of result can also be made in very abrupt contrast in different levels of light. For example, while I do not recommend this, staring at the sun or right after a camera flash an afterimage of a purple hue occurs. This can also occur through colored filters. If you stare through a red filter for a period of time, and is then removed, a green hue remains for a period of time.

Color Hues In Watercolor

Albers does most of these studies in colored paper in order to have an even amount of color throughout the object used in his studies. There are three concepts from *Interaction of Color* that are important to realize about color mixing. The subtractive mixture that is created by pigments is not as light as the lighter color nor is it as dark as the darker of the parents. The mixture result is dependent on the proportion of the colors used in the mixture. Finally, when a color is read above or below another, an illusion of space or depth is created as shown in figure 8 and 12 (2013).

In any given situation, a color can be defined by at least two characteristics: color intensity or saturation (brightness) and light intensity (lightness). In the study below of Frank Lloyd Wright, a watercolor collage was done in the three sets of complementary colors and resulting range of intermediary hues. In such images color harmony was desired, but in this color study as a whole, such harmony is not a necessity.

A case study was done with Mario Cortes' watercolor class at Virginia Tech in the Spring of 2014. The students were asked to color two complementary 7.5 inch by 7.5 in squares that would then be cut into 25 smaller squares for use in a different representation of the colors. The purpose of the project was to show how relating tones and hues could be used to make an image out of a regular grid, similarly to how pixels operate in screens and monitors. The one difference being that such screens will use RGB or CMYK to make a color-correct image, while this study was in false color. The false color image is below as figure 12.

So how does this pertain to the color theory of vegetated walls for use in prototype tool for vegetated facades? The prototype tool will have a limited palette of colors that the designer can select from, thus the limited set of colors that would be provided by the students in the study using only the six colors found in the artist's complementary pairs of red and green, blue and orange, and yellow and purple.

Why is it important to have a limited scope of colors and their complements? It is important because this makes the designer think about the relative nature of colors. Below is all four of the tiled images that were made. The left two are the ideal images, made only with colors that exactly matched the value (amount of black) in the original image. The right two reflect the realistic setting, where the tiles available could not be duplicated as needed. This difference teaches the eye to see relative differences in depth, eliminating the false color of the initial images, reading the underlying depth. It also teaches the designer how to create an image with intensive limits placed on the products available.

Figure 18: All of the images as part of the full composition.

All four of the images together a person to see the differences in using a rigorous computer program to create and image, as compared to an amateur's first attempt to read color depth without the assistance of color filters.

Figure 19: Tiled image of Frank Lloyd Wright

Since there is a limited amount of each value, the colors that are placed next to each other need to have the appropriate difference in value, but not necessarily the same color as the ideal representations made by the computer program. Through a process of making and iterating the final image, an approximate image of Wright is made out of a grid of smaller squares. Using tiles of a darker value delineates shading, while tiles of a lighter value fill brighter surfaces. It is the process of placements and then assessing the image that creates a final composition. This process will be taken to be used in the prototypical tool. If the false or not realistic color hues are taken out and only the tones of the colors remain the depth of the image is retained, still show the image. This can be achieved by color filter.

Figure 20: Black and White tiled image of Frank Lloyd Wright

This concept of creating depth with hues and tones will be important in developing the depth and aesthetic qualities of the living walls in relation to color theory, and later in the ability to represent these walls through computer simulation. These steps then will become part of the method for teaching the aesthetics of living walls in a studio environment.

Vegetated Assemblies in History

Examples of Vegetated Roofs and Walls through Time

In the process of attempting to design a contemporary building envelope, specifically a vegetated facade, it is vital to understand the historical background of such designs. Without understanding the impact designed vegetated spaces had on history and its people, contemporary projects would be without context. These vegetated spaces exist all over the world, each with a different method of implementation and aesthetic. These precedents begin to inform the designer of each aesthetic, but also about what types of local flora can be used when applied to vegetated assemblies. Every climate creates a context for the plants and systems used in a design, and this pallet of plants is critical in the design of a vegetated wall and its simulation. While this study will refine its focus to a Southwestern Virginia climate, an initial global perspective is important to the overall understanding of vegetated systems. There is something fascinating about seeing a vegetated wall, whether it is a juxtaposition of vegetation where a wall should be; an innate connection with nature; or the walls inherent aesthetic qualities, experiencing its unique nature is exhilarating.

This history of vegetated assemblies begins with the Ziggurats of ancient Mesopotamia. These temples were built in stages with each flattened terrace including plants to allow for rest on a person's journey upward. These gardens exemplified the power of a ruler as Osmundson (1999) explains, "It [the ziggurat] was completely remodeled by the last neo-Babylonian king, Nabonidus, […] in an effort to surpass the splendor of Etemenanki in Babylon," The Hanging Gardens of Babylon are another example of the grand nature vegetated gardens held. What is critical to note is that the gardens were supposedly built by the ruler, Nebuchadnezzar II, for his wife who desired and missed the landscape of her homeland. (Osmundson, 1999). While the tangible evidence of these ziggurats and hanging gardens no longer remain, the inspired grandeur of raised gardens above expansive plains in a desert must have

Figure 21: Hanging Gardens of Babylon

been extraordinary. The natural beauty of the landscape was an aesthetic quality that people admired and desired. These massive undertakings had to be considered in both as an aesthetic and engineered marvel.

Vegetated assemblies continued to be constructed in the Middle Ages and Renaissance. Mont-Saint-Michel in France, Palazzo Piccolomini and the Tower of the Guinigis in Italy, and Tenochtitlàn all continue the tradition of vegetated roof gardens. In the Industrial Age such gardens continued to be built in Germany, Russia, and the Nordic Countries. At the turn of the century summer entertainment gardens were built on the rooftops of theaters in the United States such as Madison Square Garden. Frank Lloyd Wright and Le Corbusier also designed vegetated assemblies in spite of radically different architectural philosophies. In San Francisco, Union Square by Timothy Pflueger in 1942 is a raised garden on a parking structure and was renovated in 2000 (Osmundson, 1999). The tradition of vegetated roofs continues into the present with projects such as the M2 Metro Station in Lausanne, Switzerland, the Consorcio – Santiago Building in Santiago, Chile, and Acros Fukuoka in Fukuoka, Japan, to only name a few (van Uffelen, 2011). These vegetated assemblies continue into the present and continue to be built in a variety of locations, at all scales, with many different aesthetic qualities. The use of vegetated assemblies can also be more modest in scale, for example this vegetated wall in Davis California.

Figure 22: Vegetated tower in Davis, California

These vegetated assemblies were commonly roof gardens, a horizontal application of vegetation and construction. The roof garden produces a sense of place and nature in places that were not commonly vegetated. The peculiarity and uniqueness of the raised roof gardens were found in the grandeur and infrequency of their recorded implementation. As the history of the vegetated assembly is covered, there is a dramatic shift in its complexity. If we consider that such assemblies were typically found in high-class institutions, it makes sense that vegetated assemblies were costly. In many cases these assemblies were also not reliable and prone to leaking, requiring extensive maintenance (Dunnett

& Kingsbury, 2004; Osmundson, 1999). Many of the previous examples were for the entrainment of the privileged classes, however, the Nordic vegetated assemblies (sod roofs) investigated by Dunnett & Kingsbury were used for their measurable characteristics: the abundance of sod, effective insulation, and water retention. Once again we find that these vegetated assemblies are implemented for both the aesthetic and performance qualities, however from this history, we find that vegetated assemblies are much more common on Europe, and much of this research is not available in or has only recently been translated to English.

As we approach contemporary design, the implementation of vegetated assemblies increased and the types of the assemblies begin to vary widely. These vegetated assemblies were not only chosen for scientific characteristics or a point in a system for accrediting sustainability such as LEED. These vegetated assemblies were also chosen for their aesthetic qualities and the spaces that were produced for the users. What must be understood though is that in contemporary times design must merge these two important concepts of performance and aesthetics, and produce qualities that perform in the site and bring out the quality of aesthetics desired in its existence.

Local Flora for Vegetated Walls and Façades

Plant Characteristics to Consider

In a vegetated assembly the vegetation and plant selection is one of the most important things to consider both for aesthetic and performance reasons. According to Edmund and Lucie Snodgrass, authors of *Green Roof Plants*, the initial considerations for plants include: the design intent, client's needs, expected outcomes, budget and maintenance parameters, life expectancy of the green roof, access and safety issues, location, micro and macro-environments, exposure, humidity or dryness, temperatures, medium weight, depth and composition and irrigation (Snodgrass & Snodgrass, 2006). While these considerations are specifically listed for green roofs, these considerations are also necessary for vertical green walls and green facades. Plants that are taken out of a completely natural environment and place on the façade must be tougher and less nutrient dependent. The new planting medium that is created must have a specific organic content, pH and nutrient levels, weight, porosity, and water retention

capability that suit the conditions above. Both roof and wall medium must be lighter, more porous, and less rich in organic matter (Snodgrass & Snodgrass, 2006).

The surrounding environment and geography certainly play a role in the development and success of a vegetated assembly. The heat and hardiness zones that the site is located in combined with the reasoning that site-specific temperatures are more localized than the temperatures on high-low temperature hardiness maps and do not account for micro-climates, is a driving factor for development (Snodgrass & Snodgrass, 2006; White, 2005). The climatic conditions including sunlight, wind, shade, and temperature fluctuations are critical to consider. Sun, heat, and wind are more damaging to an exposed plant on the envelope of a building and mounting plants will stress the plants. Therefore, plants selected are commonly heat, cold, sun, wind, drought, salt, insect, and disease tolerant, requiring minimal nutrients and maintenance (Snodgrass & Snodgrass, 2006). For example, if a plant is nutrient dependent, local riparian zone pollution can occur due to fertilizers that are washed out of the assembly and into stormwater (White, 2005). Furthermore, depending on the location, irrigation systems or watering may be needed (Kolb, 1995; Snodgrass & Snodgrass, 2006). The vegetated assemblies need to be considered at multiple scales in order to be successfully implemented in design and construction.

There are many different types of environments in which plants thrive. These environments can include: mountains, high-latitude, coasts, limestone vegetation, Sclerophyllous woody vegetation, and semi-desert (Dunnett & Kingsbury, 2004). Southwest Virginia is a mountain climate, though not as extreme as others. The more extreme alpine plants can be found in meadows above the tree line with shallow soils, scree slopes of greater of lesser stability, and rock faces. Depending on the direction of the slope face, plants can also be subjected to harsh sunlight or very little sunlight. (Dunnett & Kingsbury, 2004). The Appalachian Mountains are a mountain environment and this should be reflected when selecting plants for use in design applications.

These vegetated assemblies are living systems and certain issues can arise from plant selection, invasiveness and maintenance. Globalization and bioengineering also can contribute to the changes set forth in incorrect plant selection. The use of native and local species in this study is supported by the literature as a means to curb the influence of invasive species. There are a variety of things to consider including: invasive root systems, using a trial period to verify a new species, self-sowing or short lifecycle

plants, berries or wind-blown seeds, large quantities of seeding, climber and climate characteristics. Finally, maintenance such as feeding, plant protection, drainage, and weeding also influence the success of a vegetated assembly (Dunnett & Kingsbury, 2004).

Determining Plants for Southwestern Virginia in the Literature

Since this study is specifically for the climate and vegetation of southwestern Virginia, natural plant communities will be used as a guide for the vegetated assemblies to be designed later in the study. For this study the examples will show natural regions as models for types of green roofs and walls, and then the focus will shift to southwestern Virginia in USDA Plant Hardiness zones 6a and 6b.

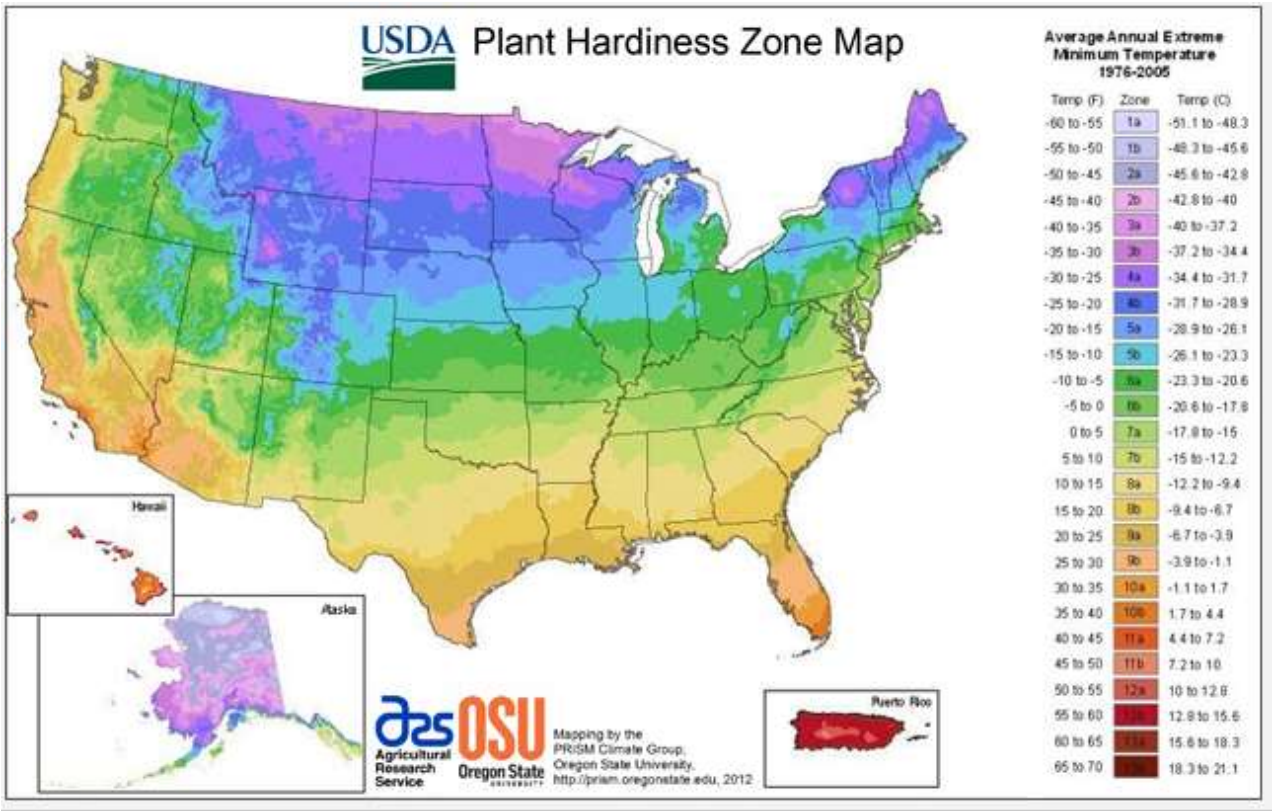

Figure 23: USDA Hardiness Zones by ARS and OSU

To narrow down the types of plants that could be used, the plant hardiness zone for Southwestern Virginia must be determined. Looking at the USDA map of hardiness zones, southwest Virginia is mainly

a mix of zone 6 and zone 7. These zones are determined by the average annual minimum temperature for an area with zone 6 at 0 to -10°F and zone 7 is from 10 to 0°F.

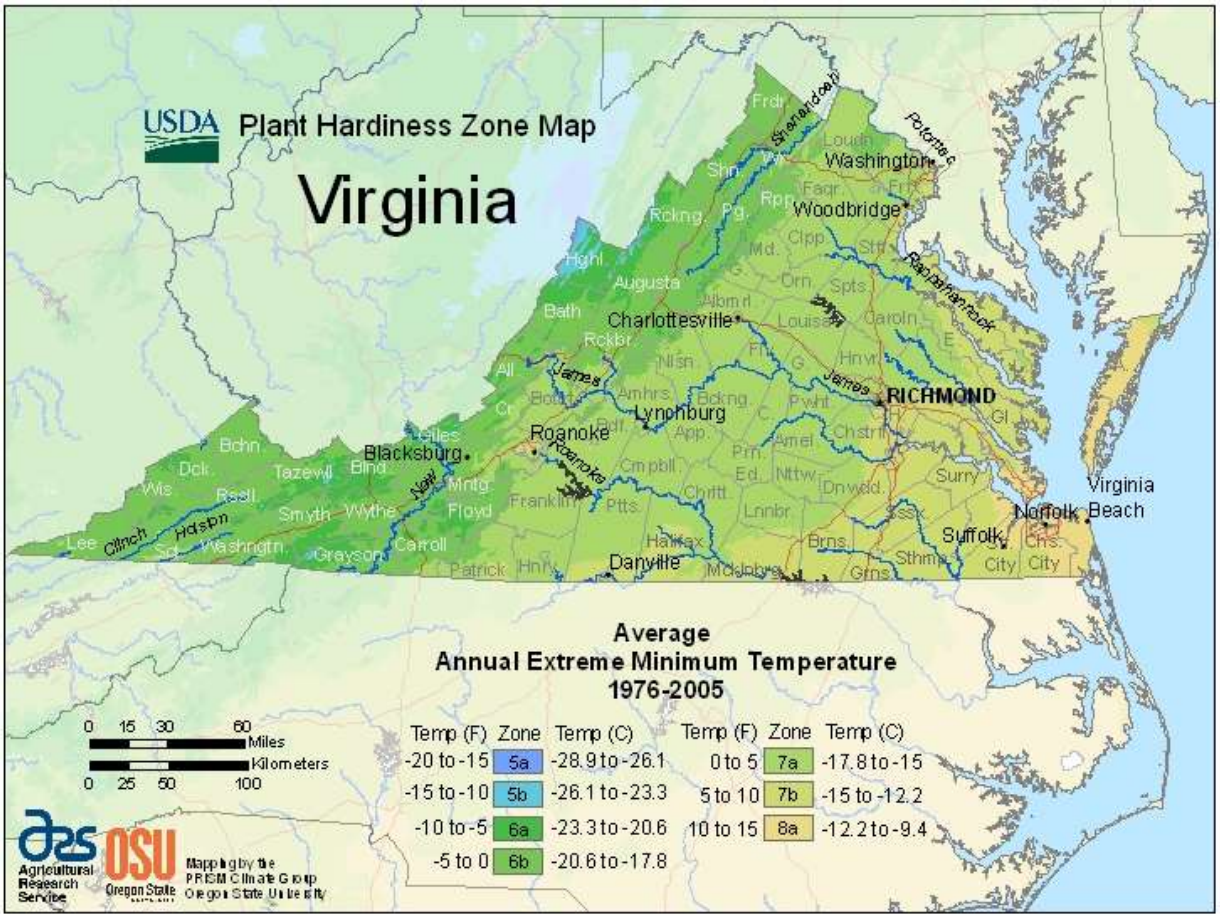

Figure 24: USDA Plant Hardiness Zone map of Virginia by ARS and OSU

In this round of plant selection the study will also look at plants that can survive harsher conditions, such as zones 2 through 5, and are perennials as well. Using a plant directory from Dunnett and Kingsbury, cross listing for plant origin or invasiveness (also in the chart below), starts with: *Ampelopsis cordata* native to southeastern US (zone 6-8), *Aristolochia macrophylla* native to the eastern US (zone 4-7), *Celastrus scandens* native to eastern North America (zone 2), *Cocculus carolinus* native to the southeastern US (zone 6-9), *Parthenocissus quinquefolia* native to eastern North America (zone 3), and *Vitis aestivalis* native to eastern North America (zone 3-9). This list of plants does not include some of the more commonly used plants in vegetated façades, such as *Wisteria sinensis* from eastern Asia (zone 4-

9). This diagram of the possible plant species is below, followed by a table of the short list of possible plants generated by looking at the literature. This will then be compared to local growers' lists of commercially available plants too how theory and application interact.

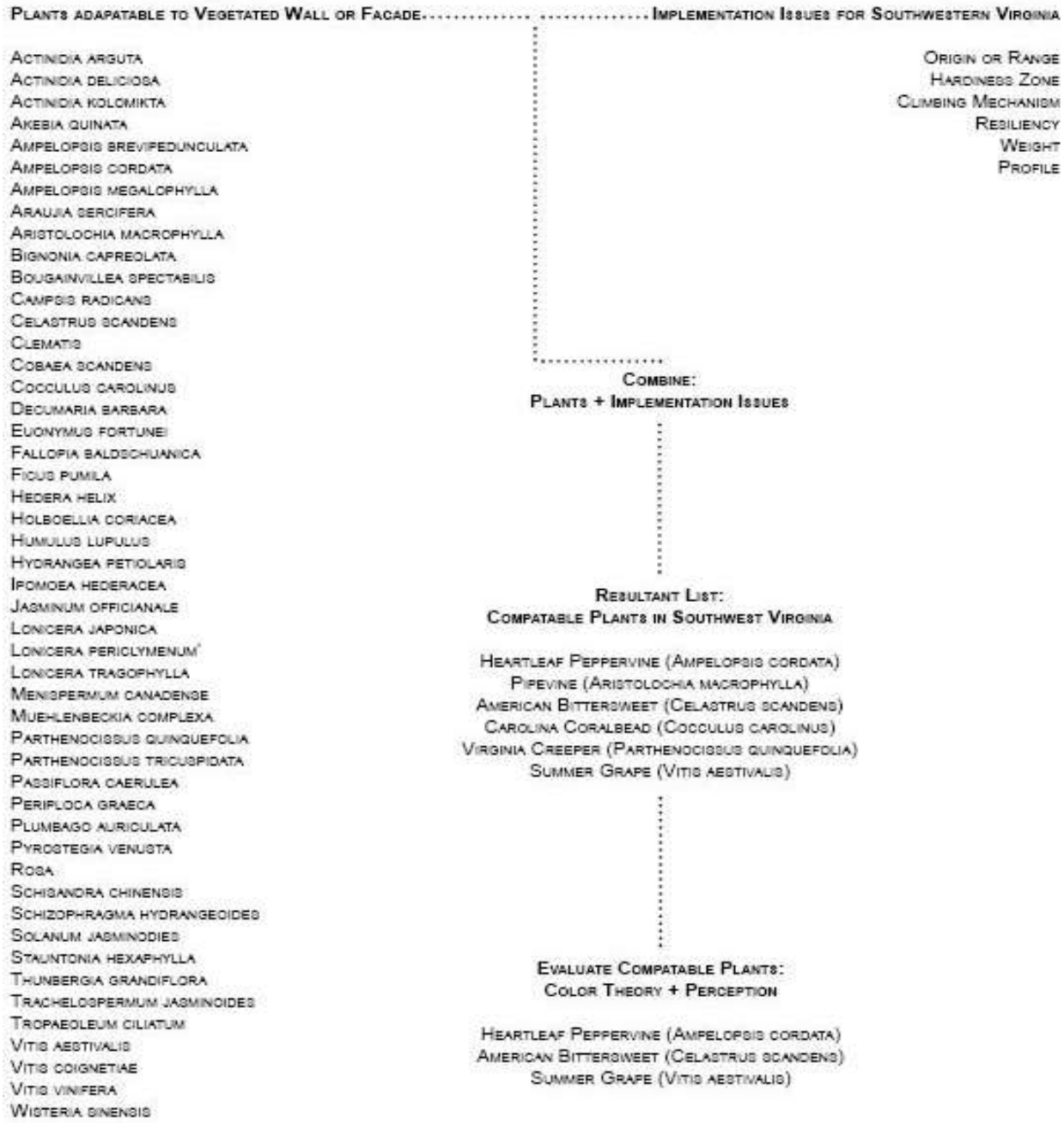

Figure 25: Method for generating the literature based short list of plants

Table 2: Working List of Plants for Use in Dissertation Explorations

Photograph						
Common Name	Heartleaf Peppervine	Pipevine	American Bittersweet	Carolina Coralbead	Virginia Creeper	Summer Grape
Scientific Name	Ampelopsis cordata	Aristolochia macrophylla	Celastrus scandens	Cocculus carolinus	Parthenocissus quinquefolia	Vitis aestivalis
Hardiness Zone	4	7	2	6	3	3
Range	S. Eastern US	Eastern US	Eastern N. America	S. Eastern US	Eastern N. America	Eastern N. America
Growth Rate	Moderate	Fast	Fast	Fast	Fast	Fast
Climbing Style	Vine-tendril	Vine-twining	Vine-twining	Vine-twining	Vine-tendril	Vine-twining

Images: plants.usda.gov with the Natural Resources Conservation Service

Short List Characteristics

The short list includes Virginia Creeper and the Summer Grape. After creating a short list of applicable plants for the study, the plants must be reviewed in depth to understand how their characteristics and growing methods could cause them to interact with each other. This interaction can be both positive and negative. For example, the colors could not be compatible, or one plant could dominate the other over time, causing one plant to die out of the system. The characteristics listed here are a combination of physical observations as well as characteristics reviewed by the Natural Resources Conservation Service (NRCS), a part of the US Department of Agriculture.

The database that is maintained by the NRCS uses a set of characteristics that helps to design resource conservation plantings, and includes growth form and growth requirements to suitability for uses. Some of the characteristics used for reviewing the morphology and physiology of the plants include: the active growth period, dormancy period, fall conspicuous, flower color, flower conspicuous, foliage

color, foliage porosity summer, foliage porosity winter, foliage texture, fruit/seed color, fruit/seed conspicuous, growth form, growth rate, height, leaf retention, lifespan, shape and orientation, and toxicity. The next set of characteristics from NRCS concerns growth requirements. These include adaptability to soil types, drought tolerance, fertility requirements, frost free days, hedge tolerance, maximum and minimum soil pH, planting density, precipitation, shade tolerance, and minimum temperature. After growth in a plant is the ability of the plant to reproduce. These characteristics include the bloom period, commercial availability, fruit/seed abundance, and periods, method of propagation, seedling vigor and vegetative spread rate (USDA, 2014). The ability of the plant to be used for commercial product will also be considered, but is not a major part of the study into which plants are useful in vegetated assemblies. Definitions of these terms can be found in the definition appendix. Each plant will be considered for many of the characteristics to determine if the plant will be useful in a vegetated assembly and if its use will not negatively impact other plants or passerby.

The characteristics that will be used for reviewing the morphology and physiology of the plants for the purpose of color theory in the study include: texture (fine, medium, bold – may be one texture during growing season and another in winter), foliage size, color, and shape, and dormant season appearance, and flower and fruit [conspicuous or inconspicuous, size, color; month(s) of appearance]. Most of these characteristics can be found in the NRCS plants database. Two plants from the previous list will be explored further: Virginia Creeper (*Parthenocissus quinquefolia*) and the Summer Grape (*Vitis aestivalis*). In regards to color documentation for color theory applications, the Royal Horticulture Chart will be used as the standard reference for plant color identification. This same color chart is used with food colorings, chemical engineering companies and fabric designers.

The plant that will be engaged at full scale will be Virginia Creeper: *Parthenocissus quinquefolia.* Virginia Creeper is commonly used for erosion control, restoration, and wildlife. It is used as a groundcover for is fast growth and open canopy. It also is a native plant of eastern climax forests. The foliage provides

Figure 26: Virginia Creeper on a block wall

cover and food for birds and deer. Virginia Creeper is a coarse (bold) textured, deciduous vine whose green leaves can turn red in the fall before dropping. The leaves are toothed and grow to be about six inches long. The vine is stoloniferous, and most active during the spring and summer, growing and spreading very rapidly, and blooms in late spring. Overall the plant is conspicuous in the fall, whereas the green flower clusters are not. The vine will have dark blue, non-conspicuous berries in low abundance in fall as well (USDA, 2014). The vine has a high resistance to drought which makes it suitable for wall application, adhering to walls with adhesive disks.

These plants could be used as models for vegetated and living walls when representing local, Appalachian mountain climate in theory using the literature. The characteristics of the plants will inform the design of vegetated walls and how the plants are introduced to surfaces and what materials are used. When reviewing local flora for use in the modeling simulations, we must understand that as designers we are attempting to reconcile two very different things. We are attempting to rationalize the natural beauty that nature provides through evolution, and model it in an imperfect binary computerized world, foreign to its existence. These plants and vegetated assemblies can be mimicked in computer simulations, but not replicated no matter how precise the model. No matter how much a designer can attempt to control for, nature will chart its own course and make every living thing unique by its own mechanisms.

Defining Native and Non-Native

Types of plants can be great in theory, but what is actually grown and distributed by industry growers in Virginia, that can be used in zone 6a and 6b? To view possible plants, it is important to not only understand who is providing the information, but what the desired outcome becomes. Therefore the hardiness zone maps provided by the USDA and not strictly man-made delineations of states will guide what is considered native and non-native in the study. Referring back to table 2 for example, a pipevine might be found in a native nursery, but American bittersweet is most likely not, whereas Boston Ivy is preferred over Virginia Creeper, but both are viable and colorful over the seasons. What this shows us is that we can be limiting the usefulness of the preliminary prototype tool by not gaining information from the growing industry.

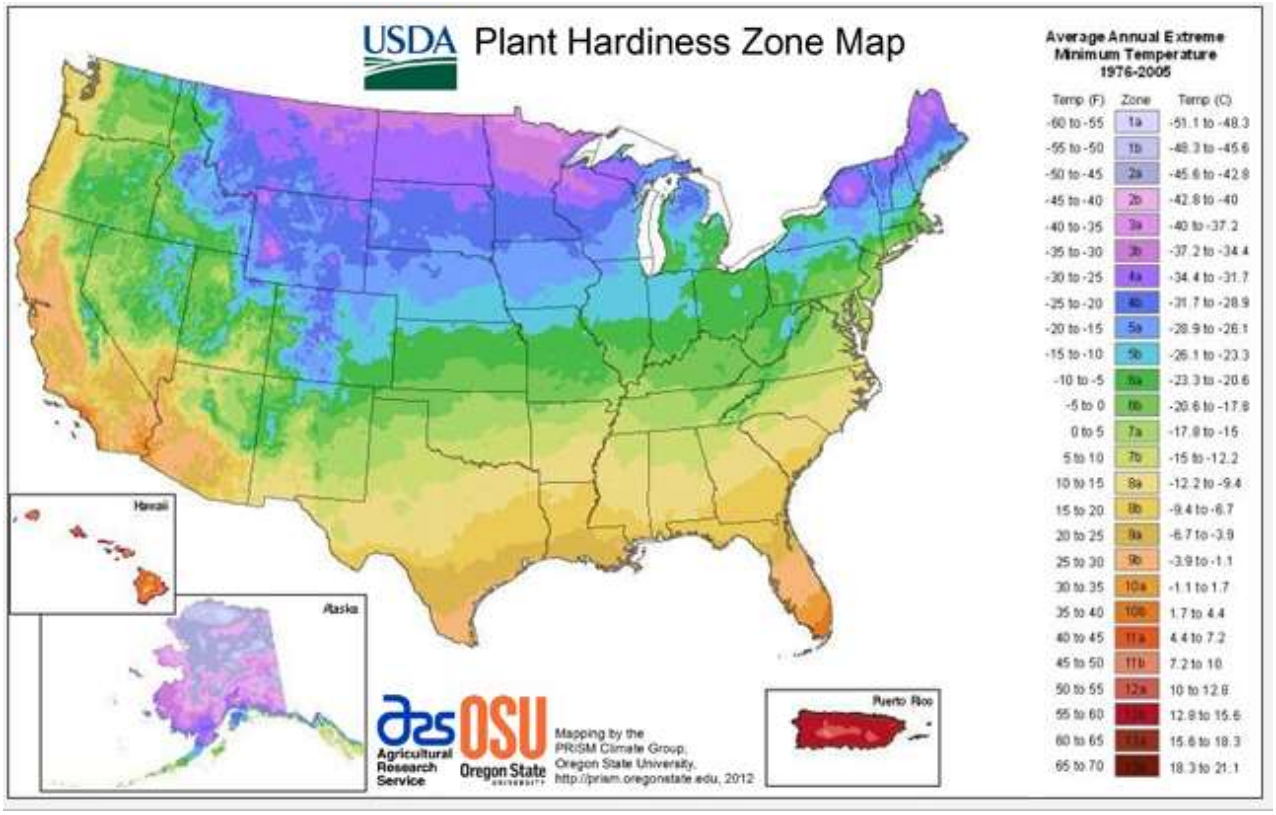

Figure 27: USDA Hardiness Zone map

To take a look at the full United States map of hardiness zones again, we find the plants native to zone 6a and 6b are much father reaching than the outline of solely “Virginia”. That leads to how to define what is native vs non-native – the study will be looking at plants for the prototype tool that can grow in the climate of a Appalachian mountain climate, specifically zone 6 as natives, while those that can grow in this climate and are not from the regions in the US, but that can grow in zone 6 are considered non-natives.

A second way to determine native plants is the type and abundance of local insect larvae that will grow on the vines. The more larvae that grow, the more birds will be attracted, weaving a web of ecology for the entire system. This concept from the work of Douglas W. Tallamy from the University of Delaware, shows another method for determining what to plant in the US mid-Atlantic region (Tallamy, 2009, 2014). A portion of an excel sheet he provides includes woody, herbaceous, and vining plants, including Virginia creeper with 32 native larvae species. The inclusion of Virginia creeper in this list is what leads it to be the vining plant to be used at full scale in the project.

Vines		
Bignonia capreolata (Cross Vine)		
Knotts Creek Nursery	757-483-6383	x
Campsis (Trumpet Creeper)		
Knotts Creek Nursery	757-483-6383	x
Clematis 'Assorted Varieties' (Clematis)		
Bennett's Creek Nursery	800-343-4611	x
Saunders Landscapes	434-263-6642	x
Knotts Creek Nursery	757-483-6383	x
Gelsemium (Carolina Jasmine)		
Knotts Creek Nursery	757-483-6383	x
Hydrangea anomala subsp.Petiolaris (Climbing Hydrangea)		
Ingleside Plantation Nurseries	804-224-7111	x
Knotts Creek Nursery	757-483-6383	x
Tankard Nurseries	800-552-2088	x
Lonicera 'Assorted Varieties' (Honeysuckle)		
Knotts Creek Nursery	757-483-6383	x
Parthenocissus tricuspidata (Boston Ivy)		
Knotts Creek Nursery	757-483-6383	x
Passiflora incarnata (Passion Flower Vine)		
Knotts Creek Nursery	757-483-6383	x
Polygonum (Silver Lace Vine)		
Knotts Creek Nursery	757-483-6383	x
Trachelospermum jasminoides (Confederate or Star Jamine)		
Knotts Creek Nursery	757-483-6383	x
Vines (Assorted)		
Bennett's Creek Nursery	800-343-4611	x

Figure 28: List of vines by VNLA

Looking at it from the grower's perspective, we find a modest list of vining plants that would be suitable for projects in the western Appalachian climate, with zone 6a and 6b. These plants are shown from the *2013 Guide to Virginia Growers,* provided by the Virginia Nursery and Landscape Association, as well as contact information.

The plants included in this list will be included with Virginia Creeper as plants to be studied for use in the prototype tool. It is important to not only include plants that will work in the tool from the literature, but those that will respond to the site and bring ecology back to the site, in an effort to re-enliven the building envelope and vegetated walls.

A Story of a Living Wall

Re-enlivenment in Designing a Living Wall: Reconciliation Ecology

Re-enlivenment and humanity are not mutually exclusive. This method of interacting with and respecting the environment, beyond reservation ecology and reservation ecology, is termed reconciliation ecology. Reservation ecology serves to save untouched ecosystems. Restoration ecology attempts to revert partially used ecosystems to natural settings. Rosenzwieg believes that these first two have reached their full potential and humanity needs to utilize the dormant form of interacting with the environment: reconciliation ecology (Rosenzweig, 2003). Restoration is looking to resurrect the past, reservation looks to adjusting the present, and reconciliation ecology looks to the future for potential. Re-enlivenment and living walls are rooted in the contextual past, existing currently in the present and have potential in the future. Re-enlivenment is a continuum that includes facets of restoration, restoration and reconciliation ecology. Vegetated walls and Living walls can move beyond the current view of many as

ornamentation and decoration using re-enlivenment principles. If these walls can create a sense of place and stewardship, they can rebuild the connection humanity has with nature.

This shows that re-enlivenment is a contextual, human condition that can mold the future. It not only suggests the returning of life to the built environment, but to provide for life and nature in the future. Re-enlivenment is an extension of humanity to interface with its own inward nature and the surrounding environment, interfacing itself with a natural context. Living walls within a community can show a possible interface humanity has with nature. These vegetated and living walls are visible. This visibility is informative, interactive, inspirational, and can transform the understanding humanity has for nature. This change is not rapid, but slow and meandering. The same patience in waiting for plants to grow exposes the resilient qualities of nature and shows the impact re-enlivenment can have on humanity in the future. Specifically, living walls can reduce the perceived loss of nature, especially in the dense built environment. Furthermore, if biomimicry can be combined with living walls, biological resiliency can be brought to the walls themselves. The story of living walls in relation to re-enlivenment hinges on not only facilitating nature, but adapting it for future potential.

Types of Living and Vegetated Walls

Ecotechnology and biotechnics are used in the design and construction of vegetated assemblies and living walls. Vegetated walls often are the literal application of plant organisms to the building wall structure. The first type of vegetated wall uses a growing medium at the base of the wall and climbers with self-clinging mechanisms to cover the surface of the wall. The other type of living wall directly covers the surface of walls with vegetation but is rooted in a separate artificial medium attached to the wall.

In the first type of vegetated walls there are many methods of wall plantings, for example: dry stone walls, stacked construction and modular walls, gabion walls, or mortared walls. Dry stacked walls are where plants have begun to grow in open spaces between the stones in pockets of soil. Modular walls are made of repeating and replaceable units that are assembled to form a wall surface and plants grow in a more regular fashion. Gabion walls are wire baskets filled with rocks. The wall is supported by the baskets, not the rocks and often there are too large of gaps and air spaces for plants to grow effectively without assistance. Commonly the spaces are filled with medium, typically on top for growth (Dunnett &

Kingsbury, 2004). These walls are actually quite common and are often overlooked as areas for design potential. There is an abundance of biodiversity even within the smallest of spaces.

The second type of vegetated wall requires use of a medium on the outward facade of the wall. There are two types of such walls: hydroponic systems and living fences (Dunnett & Kingsbury, 2004). Hydroponic systems are blankets that require a considerable amount of watering due to relatively little medium, but are much lighter. The plants root into the felt/ synthetic cloth layer instead of dirt or engineered soils. The other style is living fences. These are self-contained living walls constructed with lightweight media and geotextiles within a frame work of wood or metal (Dunnett & Kingsbury, 2004). The living fence is the vertical application of the deck and planter design, where it contains medium or other growing material between two layers. These are treated almost as screens for plantings and as temporary structures.

There is merit in addressing how vegetated walls can be an adaptive form of biomimicry directly for humanity's use and then can become a living wall, an enlivened habitat for life. These controlled and adapted vegetated walls have impacts on the built environment not only in terms of performance, but also in a difference of aesthetic. Typically, very few species of plants are directly planted onto walls due to their destructive nature, both superficially and structurally. For this reason plants are typically used on non-structural walls. These vegetated walls and façades change during the seasons. Traditional styles of climbers in Europe were self-clinging and applied directly on façade. The tendrils of the climbers often attached to the weaker points of the façade, such as grout in brick walls and deteriorated it over time. In order to ensure the stability of the façade, the modern style of vegetated walls and façades uses separate structures such as cables or trellises, and a variety of plant species (Dunnett & Kingsbury, 2004). It is also noteworthy living walls can be applied to interior spaces as well as exterior walls.

Benefits of Vegetated Façades

These vegetated walls and façades change during the seasons. Traditional styles of climbers in Europe were self-clinging and applied directly on façade. The tendrils of the climbers often attached to the weaker points of the façade, such as grout in brick walls and deteriorated it over time. In order to ensure the stability of the façade, the modern style of vegetated walls and façades uses separate structures such

as cables or trellises, and a variety of plant species (Dunnett & Kingsbury, 2004). There is potential aesthetically for vegetated walls and façades as walls typically are more visible in the built environment than roofs. According to the work of Jeffery Price at the University of Maryland, the qualitative and quantitative effects of vegetated assemblies have produced positive results, such as reducing solar gains and air pollution, mitigating stormwater runoff, and improving quality of life (Price, 2010).

A study by Manfred Köhler, showed the potential of vegetated roofs to maintain some types of human planted species, but also a much larger set of volunteer species that rooted into the systems. This set of 90, 1.2 meter square containers utilized on soil mixture and maintained 7 of 22 planted species, but allowed 24 other natural species (Rosenzweig, 2003). If this sort of activity is happening on the vegetated roofs of buildings, could it not also be used in the walls as well? These walls serve as a scaffold of our chosen plants to grow but also species from the built environment that come to thrive with our own. The mix of human and natural systems forms the success of reconciliation ecology and living walls.

According to the work of Jeffery Price at the University of Maryland, there are numerous benefits produced by living walls: they reduce solar gains and building temperatures; they absorb air pollution, mitigate storm water runoff, and improve quality of life (Price, 2010).

In regards to the reduction of solar gains, climbers can reduce the temperature of the building envelope more effectively by shading large areas of the façade (Köhler, 1993). Laura Schumann, from the University of Maryland, developed a retrofit shading system called the 'Green Cloaks'. This system was suspended over a structure in order to shade it and the interior air temperatures in un-conditioned structures were reduced (2007). The cooling of the façade is further supported by the work of Millward in 2014, stating that vegetation can reduce the solar gains of buildings, depending on the leaf area, plant size and proximity to the building, and plant location to the solar path (Millward, Torchia, Laursen, & Rothman, 2014). Work by Steven Sandifer at UCLA finds a series of positive results to lowering the temperature of the façade to almost that of the ambient temperature at 12-14 inches thick, eliminating the effect of color, that vines on western facades can reduce the problem of western heat gain, and spaces such as vine-covered pergolas can provide more comfortable exterior conditions (Sandifer & Givoni, 2001).

Vegetated facades also are a benefit in the winter by reducing heating demands from wind chill (Peck, Callaghan, Kuhn, & Bass, 1999). The ability for vegetated walls and façades to shade the building envelope can reduce the urban heat island effect (Akbari, Pomerantz, & Taha, 2001; Bass, 2001). Vegetated walls can cool the building envelope through the latent heat released by evapotranspiration performed by the plants during photosynthesis.

Price maintains that the benefits are not limited to heat flows between the building and the surrounding environment. They can trap dust and pollutants into plant material. For example heavy metals can be taken out of rain and stored into dead tissues. The ability to trap contaminants is greater with larger leaf areas (Köhler, 1993). This reduction is most evident near ground level, in which particulates are deposited and retained in plant tissues (Thoennessen, 2002).

Vegetated facades can reduce damage from driving rain and hail and shade susceptible materials from ultra-violet light (Dunnett & Kingsbury, 2004). Furthermore, experiments and computer modeling have shown the capacity for vegetated roofs and walls to retain storm water (Grant, Black, & Jones, 2014; Roehr, Laurenz, & Kong, 2008; Schumann, 2007; VanWoert et al., 2005). These vegetated walls also slow runoff from urban environments (Tilley & Schumann, 2008). The vegetated materials can also begin to create new habitats for animals and insects. Climbers can be a benefit to wildlife, for example, birds and bats which prey on insects that live among the plants (Dunnett & Kingsbury, 2004; Lundholm, 2006). While vegetated walls can bring wildlife back to harsh urban conditions, they can also help the quality of life for residents. For example: the view through a window of a natural scene positively influenced recovery from surgery (Ulrich, 1984). Living walls bring nature back into the urban landscape producing an aesthetically pleasing and visually interesting living membrane to the urban built environment.

Types of Walls and Attachment Mechanisms

From all of these benefits that vegetated walls can provide, how do they interact with a wall and its materials? It is a balance of these benefits of reducing temperatures and providing habitat for animals against that of the integrity of building envelope that creates either a great success or a dramatic failure. The type of vine is either self-adhesive or matrix dependent and this becomes critical in determining what

types would be useful for, or safe for different materials. The most critical aspect of any of the types of plants is that annual maintenance be performed to remove plants from undesirable location on the structure.

Plants that are on a separate matrix from the building structure are typically vining or twinging vines and are not detrimental to the façade. The self-adhesive vines need more scrutiny. There are two different types of adhesive mechanisms: some cling to the surface with holdfasts while others a much more aggressive with rootlet systems. Both of these two types of clinging mechanisms cling directly on to the wall and do not have a separate structure (Niemiera, 2014).

With self-adhering vines, two material groups are made: masonry and everything else. Masonry is excellent for self-adhering vines, although rootlet systems will get into cracks from disrepair and can destabilize mortar over a very long period of time. Holdfasts are a safer form of the clinging vines. Both types should be treated as a permanent vegetated screen on the building. “Everything else” includes facades such as stucco, wood and shingles. Climbers on these surfaces can retain moisture and cause rot. If the building surface is not made of masonry, it is recommended to use a matrix that the vines can grow on separate from the building itself (Niemiera, 2014).

The work of Josh Stoneman makes a few suggestions on what types of vines might be useful for the direct use on buildings as compared to using a separate matrix. He looks at English Ivy (*Hedera helix*), Boston Ivy (*Parthenocissus tricuspidata*), Virginia Creeper (*Parthenocissus quinquefolia*), Trumpet Creeper (*Campsis radicans*), and Creeping Fig (*ficus pumila*).

English Ivy is an invasive species and can smother other speices, thus it is not recommended due to its ecological impact and its very aggressive rootlet system. Boston Ivy is native to East Asia, but does not grow over other species and is not classified as invasive, thus it is a good chice for direct application on buildings since it uses the holdfasts and not rootlets. Virginia Creeper (*Parthenocissus quinquefolia*), is a close relative of the Boston Ivy, native of the Eastern US. It uses holdfasts as well and it good for direct applications with annual maintanence like the Boston Ivy. Trumpet Creeper is very aggressive with adhesive stems, thus it is good for matricies separate from the building. The Creeping Fig is not suitable for a Zone 6a, b climate, but is a good choice for direct applications if kept away from paint and wood (Niemiera, 2014).

From this list and the list from the Virginia Nursery and Landscape Association, a number of vines will be picked and matched for use in the prototype tool, as some of the vines overlap on the two lists and should be considered highly useful for inclusion in the prototype tool. Specifically, Virginia Creeper (*Parthenocissus quinquefolia*), will be used in tests at full scale.

Case Studies

The examples shown below highlight how humanity can provide or design places and spaces within the built environment intentional or unintentional. The combination of potential habitats and the built environment set the stage for reconciliation ecology. This potential can then be translated to the concept of the living wall, allowing it to become a facilitator for plants and animals, creating a new type of ecosystem in the built environment. The analysis of such living walls can provide one of the reasons for why humanity could change its relationship with nature from that of dominance and destruction to that of appreciation and protection – embracing biophilic qualities.

Patrick Blanc: Series of Living Walls

His projects are high profile vegetated assemblies which use a variety of plants to influence color and provide a sense of awe. This sense of awe is not only found at a biophilic level, but also for the potential these systems have to bring nature physically back to the built environment. His work's goal was to replicate what was found in nature, not by a singular geographic region, but from an entire climatic range. There is merit in addressing how vegetated walls can be an adaptive form of biomimicry directly for humanity's use and then can become a living wall, an enlivened habitat for life.[i] These controlled and adapted vegetated walls have impacts on the built environment not only in terms of performance, but also in a difference of aesthetic. Typically, very few species of plants are directly planted onto walls due to their destructive nature, both superficially and structurally. For this reason plants are typically used on non-structural walls.[ii] Therefore, Blanc created a separate system for the plants to interact with that was not the structural wall and allowed the plants to fully interact with the substrate of synthetic cloths.

There is one project that shows the development of Blanc's vegetated wall in regards to re-enlivenment: the Quai Branly Museum in Paris in 2005 (Fig. 30). The façade of the museum was for the interaction with applied nature. Blanc worked under the premise of re-introducing humanity back to nature. When asked about protecting the vegetated wall from people, Blanc describes that he argued against a barrier between people and the vegetated wall, citing previous experience that most would be respectful of it. As with anything new or unknown, the neighbors were not sure of the vegetated wall in the

beginning but now defend the project. He also had the biodiversity of species in the wall reflect the cultural backgrounds of the artists which ranged from Africa, India, Southwest Asia, and the Oceania. The species used come from the main temperate zones around the world which reflects a similar climate to Paris. He also believed that the plants can also grow back if removed or disturbed (Blanc & Lalot, 2011).

In terms of the larger project, the plants were an added feature, that the wall is a true façade, and the project needed to remain within a small budget. This is often the case with projects where the vegetated wall is considered an additional expense. Routine maintenance of pruning around the windows is needed or else the plants would grow over them completely (Blanc & Lalot, 2011). This shows that the composition created by the plants is inherently about the presentation of the plants that leads to the perception of the installation. All of the plants have different values and sizes create depth, where smaller and darker plants recede while lighter and larger plants come to the foreground.

Figure 29: Mar Vegetal, Quai Branly Museum, Nov. 2009

The project covers 8600 square feet of façade with garden with taller shrubbery at the top to soften the façade edge (Blanc & Lalot, 2011). In the built environment plants can provide visual stimulus and break the redundancy of large walls. There are also added educational opportunities and visual impact for the public. For example, Blanc deliberately plants walls to teach others the potential vegetated walls contain. This is a design choice and aesthetic as to deliberately or inadvertently create vegetated habitat for plants in the built environment.

A majority of people live in cities and more will move to increase the population there, combined with an overall increasing world population resources will become limited. Growing plants vertically on a wall is a completely different adaptation of a living nature, now applied to a wall. This fascinates us.

Humanity has started to adapt nature to its own desires, mounting it to wall systems specifically designed for implementation on walls. If we won't protect the original nature earth has provided, how can we adapt it to our own constructed environments, not allowing it to fade completely from view? By increasing visibility we can perhaps re-introduce its importance in the human mind and then re-enliven the places in nature that we ourselves come from, and owe. The wall is the threshold between the exterior and interior, becoming the mediator between nature and the man-made environments. These walls can become living wall, even living screens that reduce the division between man and nature.

University of Califonia at Davis – Organized Growth

These examples show the different types of vegetated assemblies that can be used to preserve materials that are not suitable for directly clinging vines as explained previously. Masonry is a great candidate for direct-clinging vines, while wood and paint, and shingles are not. While traveling through Davis, California, there were a number of examples that illustrate this point.

Figure 30: Vine covered trellis

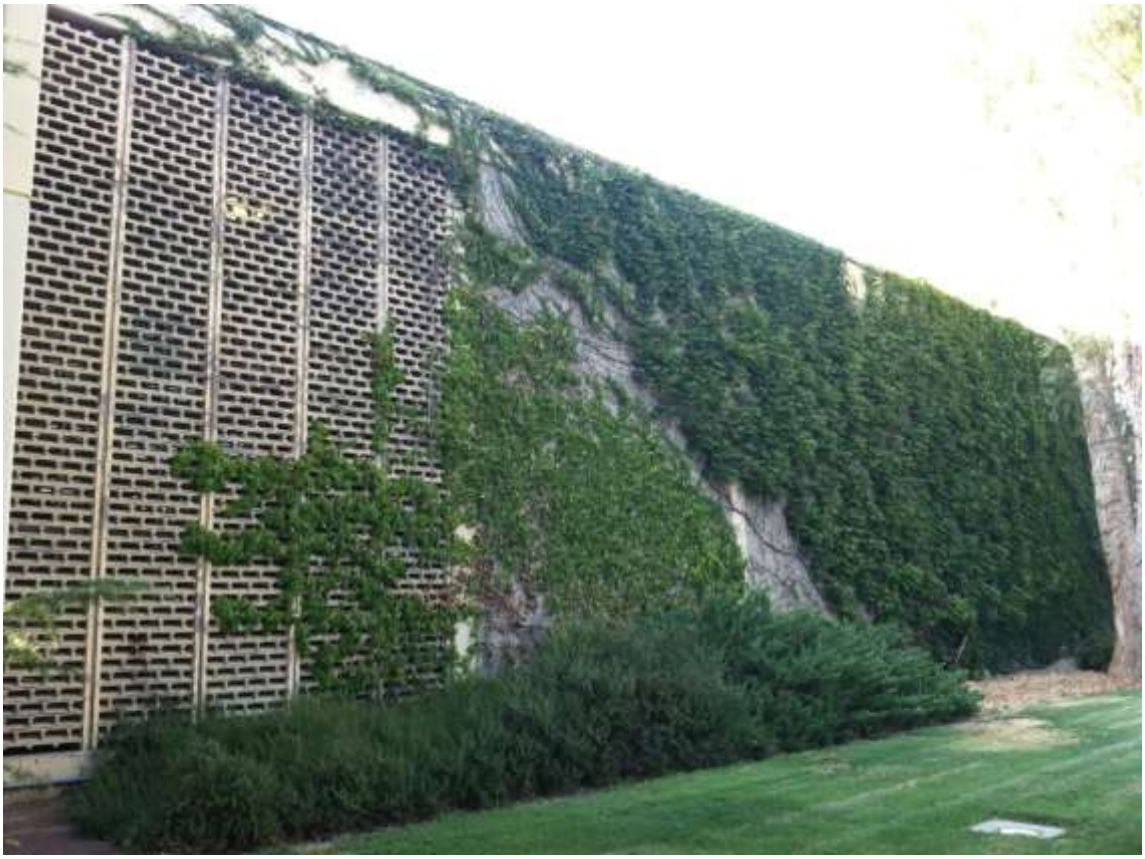

Figure 31: Vegetated matrix over siding

Figure 32: Vegetated wall on UC Davis campus

These examples from Davis show each of the three concerns in using vegetation on walls. Figure 31 on the previous page, is a separate trellis structure for the vines, though it is a twining plant, not a rootlet based vine. Figure 32 shows direct-clinging growth on structural concrete and a concrete block vent, which shows that maintenance is needed as to not cover them completely. Figure 33 shows a separate matrix over a façade which would not be suitable for a direct-clinging vine.

Virginia Tech Campus Growth - Opportunistic Nature

When we are not facilitating nature in the built environment how does nature take hold in localized areas? Currently, the majority of people live in metropolitan areas, and larger and faster growing super cities of population of 1 million or more will continue to appear (Adams, 1994). These cities are the built environment. They have waterproofed ground as sidewalks and paved surfaces. They have lower water tables and less infiltration. They have disturbances to the environment which yield more erosion especially during construction. They have streams and riparian zones modified for increased flow during storms. They alter climates with differing wind and sun exposure and great pollutants such as greenhouse gases and acid rain (Adams, 1994). They have increased noise issues, but when available humans have tendencies to enjoy natural sounds over that of man-made noise (Adams, 1994; Dawson, 1988).

This built environment can limit the biodiversity of plants; however planned interventions such as Blanc's walls and other opportunistic plants can increase this lack of biodiversity. Designers can implement vegetated systems that mimic the nature of established ones as compared to opportunistic nature that happens to take hold given the chance. What is nature and should or could it be incorporated into cities? What position does the built environment, or the civilized activity of design have in response to or in relation with nature (Eckbo, 1969)?

These questions still have importance today and into the future. As technology progresses designers not only have the opportunity but also the responsibility to reflect on the past in order to have an informed design for the present. While these questions are not tied to technology directly, the questions are useful in determining how we as designers use or allow nature to be present in the built environment. The method that Patrick Blanc uses in creating vegetated walls is entirely different from how nature manifests itself in other built environments. In the past nature has been excluded from the city, now the question should be how can we not only include it, but then adapt it to humanity's needs? These questions start the beginning for how nature can be approached in design.

Owen Manning, in *Nature in Cities*, describes nine tasks or questions that the designer can begin to work from: exploit the full potential of the site, conserve or develop diversity of habitat; encourage a full range of organic life, encourage the full cycle of growth from birth to decay, develop balance self-sustaining communities, control the system of management, create maximum variety of opportunity for

man and nature to coexist, create a coherent landscape structure and design in four dimensions (Laurie, 1979). The designer needs to look at the site and habitat diversity and determine how man interacts with nature, building in the possibility for flexible designs in the future. Much of the thought on nature in cities stems from the naturalist movement in the 19th century. It provided the mindset for including natural or countryside scenery to be adapted into the built environment (Laurie, 1979). Is it important to take advantage of the example nature has provided for us that we may learn from its worth. Designers should deliberately and intentionally create space and habitat for plants. Often plants do not need help to grow.

Plants can enhance and bring life back into the built environment. If the designer can understand the facets for why and how plants are successful even on concrete and stone surfaces, then a deliberate attempt to create a living wall is closer. There is a vast biodiversity that has been recorded on older walls, suggesting that plants do not necessarily damage the structure and could be incorporated into the aesthetic qualities of the built environment. Plants look for irregularities of small ledges to grow from as this mimics cliffs and crevices (Laurie, 1979). These cracks are often inhabited the more irregular a wall is, or has places to grasp gives more plants (Segal, 1969).[iii]

The following images show examples of plant growth around Blacksburg and surrounding areas based on both deliberate and unintentional growth. The campus of Virginia Tech in Blacksburg, Virginia creates an unusual density in a rural landscape. The core of the university has a larger scale of buildings with an adjacent downtown that dissolves into surrounding suburbs that quickly disperse into rural farmlands. The density of Virginia Tech allows for examples of both the built environment and its nature.

These photographs show four instances where plants were deliberately brought into the landscape to benefit the built environment. Figure 34 is outside of the Architecture building on campus. Over time, the ivy covering this wall has been very successful. Figure 35 is outside another residence hall near a loading dock area. Unlike the vegetation in figure 34, these vines have not climbed the fencing framework. All four of the figures above show how vegetation responds to the physical environment, especially in regards to orientation and sun exposure. While vegetation growth is also determined by plant species, sun exposure can actually hinder growth. However the environments due to the orientation of the alcoves and the coverage from surrounding vegetation drastically effects how vine grow in the space. Figure 36 shows how the physical environment can guide vines up a wall in a certain way. In this

instance the vines have followed the groove made by the concrete masonry units and then begun to spill over the top. Figure 37 shows how the built environment can influence vine growth. Condensation from the pipes of the air-conditioning units provides a steady source of water, and the vines have grown the thickest further back in the alcove where there is less harsh sunlight. There is a cord that runs along the upper left side of the picture and the vines have followed the cord, actually leaving the wall.

What can these examples of vegetation growth show us? Plants are particular to the site in which they live. Each kind of plant has a particular niche that allows them to be most successful. When given the correct conditions plants are fast growing and tenacious, especially vines and crawlers. But the conditions that we attempt to mimic and create must match the species of plants designers want to implement. As shown best in figure 35, designers cannot mix up types of climbing mechanisms and attachment structures while not providing water, adequate amount of sunlight and space. This sounds like common sense but each plant is particular to its species' needs and the conditions given by the built environment.

Figure 33: Boston Ivy vine covered concrete walls

Figure 35: Boston Ivy on fencing matrix

Figure 34: Virginia Creeper in concrete blocks

Figure 36: Vegetation on stone walls between buildings

The Need – An Adapted Living Wall

Humanity needs to understand the impacts it has on the environment and how these pressures are affecting the biodiversity of both the built and natural environment (Tisdell, 1999). It is not only conservation that needs to be addressed, but the re-enlivenment of the built environment. The living walls that designers implement must also enrich the lives of those who are around them. Biodiversity is important to the mental well-being of people in a space. The study by Ulrich in 1984 regarding the view of nature from a window in hospital patients shows us that we have the biophilic connection to nature. This connection is not always overt, but often ingrained in our psyche. It is the re-introduction of people to nature by allowing to see, to touch, and to interact with vegetated and living walls that make these projects so important. If humanity remains separated from nature or the impression of nature, it may forget the potential that nature has to give. We are re-enlivening humanity, not only the nature we seek to employ.

Computer Aided Design

Computer Aided Design (CAD) is a combination of two things: first that a type of software is used to design, and the mechanical hardware on which software operates. CAD is, “the use of computer systems to assist in the creation, modification, analysis or optimization of a design,” (Narayan, 2008). The computer and installed programs (software) are tools that help designers to design. Depending on the task at hand, CAD can be a great resource. However, not all design should be done on the computer alone. In this study CAD will be used as a part of a larger method of designing and in the representation of vegetated walls. Designing in CAD programs is not better or worse than only designing by hand with a pencil, but that both computers and analog have different strengths, weaknesses and merits. It is up to the designer to know when and how to uses these different methods appropriately. The design method that will be developed in the study will take advantage of the opportunities that technology grants designers without relying on it completely.

Four programs that will be explored during the study include: Photoshop, Rhinoceros, Grasshopper, and Google Sketchup. There are multiple programs as designers and students need options, as not all are comfortable with all types of software. Also technology and software evolve quickly,

changing with great speed. These programs will show possible ways of representing vegetated and living walls with the main focus being in methods used throughout the whole process of designing such walls, rather than the specific programs themselves. More information on the use of the programs will be included in the later parts of the study.

Photoshop

The first program is Adobe Photoshop. Photoshop allows designers to augment and create images as a post-rendering program. This means that the conceptual part of the design is completed and now changes are made for its final representation as an image. Adobe, the manufacturer of the product describes Photoshop as the ability to, “bring out the best in your digital images, transform them into anything you can imagine, and then showcase them in extraordinary ways,” (Adobe, 2014). Photoshop has the ability to finalize images intended for others to view, not as a method of the early design process. Its flexibility is only in two dimensions as a raster graphics editor. This simply means that images can be edited and then saved again in the new form. It is also very important that when choosing programs the designer be able to use the software effectively. Programs such as Photoshop have developed user interfaces that help to eliminate this learning curve when starting to learn new programs (Morgan, 2014).

Rhinoceros

The second program is Rhinoceros or Rhino. Rhino allows designers to work in 3-Dimensional spaces to create objects. Rhino can “create, analyze, document, render, animate, and translate NURBS curves, surfaces, and solids with no limits on complexity, degree, or size. Rhino also supports polygon meshes and point clouds,” (VisualARQ, 2014). All of these tasks Rhino does allow the designer to manipulate space freely. The flexibility the program has because of the free manipulation of space makes it simpler to learn and is readily available to students. Furthermore, since the program is open, meaning that users can manipulate the program itself, many plug-in have been created to advance the capabilities of the program. This will become useful in the development of a design tool and method for representing vegetated and living walls as many programs do not allow this manipulation of the program. Some of these manipulations also known as ‘Plug-ins’ are available through Rhino’s website and include DIVA-for-

Rhino which is a sustainable design radiance and day simulator; Grasshopper which is a importing, exporting and generation of BIM and structures; and VisualARQ which is an architectural Plug-in for Rhino (Rhinocerous, 2014). The second of these Plug-ins, Grasshopper, is an important part of developing the method for designing new vegetated walls and their assembly structures.

Grasshopper

Grasshopper is the third program or 'Plug-in'. Grasshopper is, "a graphical algorithm editor tightly integrated with Rhino's 3-D modeling tools," (S. Davidson, 2014). Grasshopper uses a graphical layout that helps designers with no previous background in designing complex structures to become acquainted very quickly with spatial forms in Rhino's that are more difficult to create. The program uses what are called form generators and connects them visually on a user interface (S. Davidson, 2014). At this time Grasshopper works with Rhinoceros 4, which will be the version of Rhino that will be used in the study.

Google SketchUp

Google SketchUp is the fourth program. This program is a simpler and less costly version of Rhino and is a 3-Dimensional representation program. Depending on the version it is even offered for free to download. The user interface is simple and a quick tutorial allows the user to start designing almost immediately. The program uses a type of artificial intelligence to make design even easier, going off of what the designer has already done in the space. For example if the designer uses a certain dimension frequently, SketchUp will remember it. Also there is a large library for objects and models that the public has created and allowed others to use, rather than making everything yourself (Zukerman, 2011). Once again this program was chosen for its ease of learning for new students and designers.

The Wicked Problems in Studio

The 'Wicked Problem' in the Design of Vegetated Walls

Design is an iterative process that develops ideas over a series of explorations to propose a designed response. Design is a part of a three way balance with the humanities and sciences. Considering the importance of nature and biomimicry in the design of vegetated and other living walls,

technology is a result of design synthesis from iterative explorations. The proposal to explore vegetated assemblies in relation to color theory is a ‘wicked problem’ that cannot be solved by only approaching it from the perspective of architecture. Multiple perspectives including architecture, horticulture, art, and biotechnics must be combined to make an appropriate designed response. The question remains: from all of these subsets of different problems, a problem reveals itself: how can designers synthesize vegetation/plant growth, color theory and design decision-making to be better integrated into the design process of ideation, representation, and iteration?

Preliminary Conclusions and Significance from the Literature Review

It is important to pass on what we, as researchers and scholars, learn and know. The information that we gather as educators should not be kept in a shelf, far away where students cannot find or learn from our successes and failures. Without sharing the knowledge we learn from research and our own experiences, we cannot expect our student to improve past our own abilities. As educators this should be our primary mission. Using the phenomenological stance, the most effective way to pass information is through the experience and our interactions with the world around us. It would be detrimental to the development of students if they do not interact with their surroundings, while expecting them to design and develop a thesis on Architecture. This study hopes to combine both research and representation so that each relates to a builds off of the other. The significance lies in the ability for research in vegetated and living walls to be transformed in a story, which can be told and shown to others, bringing forward unknown potential.

It is the story, the process of how a concept goes from ideation through iteration to become a viable design, which is the most informative to a beginning designer. A designer must have the experience, over time to synthesize technical knowledge with the conditions at hand. These ‘wicked problems’ in design are the reason why Architecture and other deign fields are not problems to be solved, but ideas waiting to be given context. This context is provided by the past, present and the potential future as a continuum of experiences by humanity. Nothing can be truly an original thought produced out of a vacuum, a void of experience. This is not to say that anything that is designed is not original, just that a

designer's body of work needs to be authentic, not copies of previous work. This is accomplished through the iteration of many ideas that yields a new story to be told.

Design is a continuum, that previous work and research informs present studies. Personally the idea of bringing nature into the built environment is not new. The deck and planter project (in the Types of Living and Vegetated Walls p.54) is only one example of where my design has attempted to re-introduce plants into the built environment. In the example it was bringing gardens back into abandoned urban lots. These ideas crossed disciplines and asked revealed new issues of how to represent these ideas to others and how do we mimic natural environments in the built landscape. If humanity remains separated from nature or the impression of nature, it may forget the potential that nature has to give.

Therefore it is important to consider how we as humans will reconcile our interaction with the environment what the future will hold. There should be a way to teach living walls to others in the studio environment and consider a multitude of design archetypes such as a chapel, house, school, airport, tower, and others. Designers need to bring everything together and consider a method for technology and CAD design to mix with vegetated walls and biomimicry. These designs can be done by hand or in the computer and could synthesize the concept of a new kind of living wall that can be represented in the new design method and process. Design is that continuum which considers both past projects as references that can inform future iterations of a process. If humanity is going to lessen its impact as well as re-enliven its built environment, it will need to do so with the re-introduction of responsive architecture which mimics the nature it rejected in the past, through living walls.

3

Methodology: A way of Implementation

Methodology

There will be a number of stages in the development of the prototype tool for representing the vegetated walls and living walls as well as the method in which to teach this topic to others. The process starts with a review of the literature to find established methods of defining, observing/testing, and interacting with color theory, plant biology, aesthetics, and design decision making through representation. The synthesis of this literature review revealed the importance of the interactions of seemingly unrelated topics and how these interactions yield new insights. From this literature review, a concurrent project involving the construction of an electric car changing garage will review the process and results of full-scale construction with a north-facing vegetated wall of one plant species. A photo analysis of the garage and the vegetated façade will inform the prototype tool. From the literature review and this immersive study of the garage, a process and method for how to represent such projects in advance will be determined as the beginning for the prototype representational tool. Therefore, this design method will be will be in part a method of representation and a method of teaching vegetated walls and living walls to others. The immersion of students and other colleagues will serve as beta testing the representational tool to test its usability toward improving design decision-making. This stage will use myself and 2-3 other “designers” or colleagues to develop the tool. A final member checking or Delphi stage will be completed to gain a consensus for the positive impact on design decision-making using a maximum variance sample of 6 to 12 designers using interviews. The following chart shows the different categories these designers could reside.

Table 3: Experience and Method Used in Vegetated and Living Walls

Maximum Variance Sample Experience and Method	Computer Design	Analog / Hand-Drawn
No Previous Experience with Vegetated Assemblies		
Previous Experience with Vegetated Assemblies		

Of course there would be more than one way to represent vegetated or living walls. It would be beneficial to determine some method of how to start the ideation, representation and iteration process. This process and resulting tool would be triangulated for effectiveness and usefulness through the interpretation of the researcher, immersive case studies and interviews, and a member-checking or studio phase. The best method would be to have multiple attempts at running a Delphi or studio situation to receive more experience in the teaching method and refine the representational approach and prototype tool.

The more preferable of the two would be the Delphi, allowing for a group of 8-12 experts to use the representation tool for a number of different design cases. They would sort through the steps necessary to design the vegetated systems according to color theory, plant biology and ecology, biomimicry and aesthetics. Afterwards questions and information gathered at the meeting would be used to inform another iteration of the prototype representational tool. What is more probable is the development of a studio with 8-12 students who would use the tool as a part of their design work over the semester. The students would maintain a journal about working with the tool as they work through a design prompt related to the concept of vegetated assemblies. Then at the end of the semester the work would be presented and final thoughts on the prototype design tool would be recorded. The journals would be turned in after grades were established to not negatively impact their performance and critical analysis of the prototype tool out of concern for their personal assessment for the studio. As with the Delphi, afterwards questions and information gathered at the meeting would be used to inform another iteration of the prototype representational tool. It is the whole process of developing and then analyzing the tool and its implementation in a studio that is critical to the development of the prototype tool and design process for the future education of designers.

The diagram in figure 38 visually summarizes the methodology of the study describe above and each will be explained in full throughout the chapter beginning with ideation and culminating in the prototype tool for the representation of vegetated assemblies.

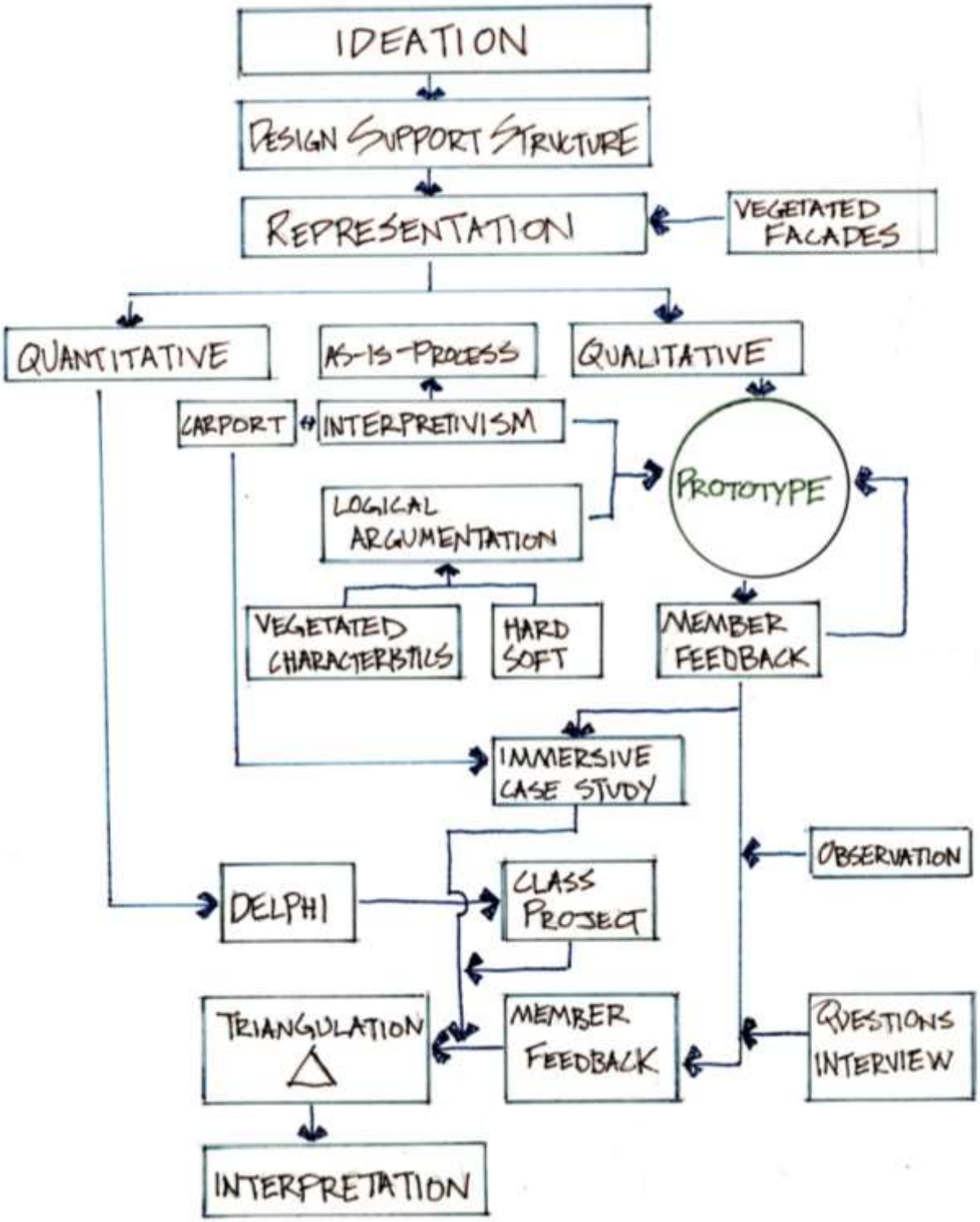

Figure 37: Theory Map for Design Methodology

Ideation: Philosophical Method

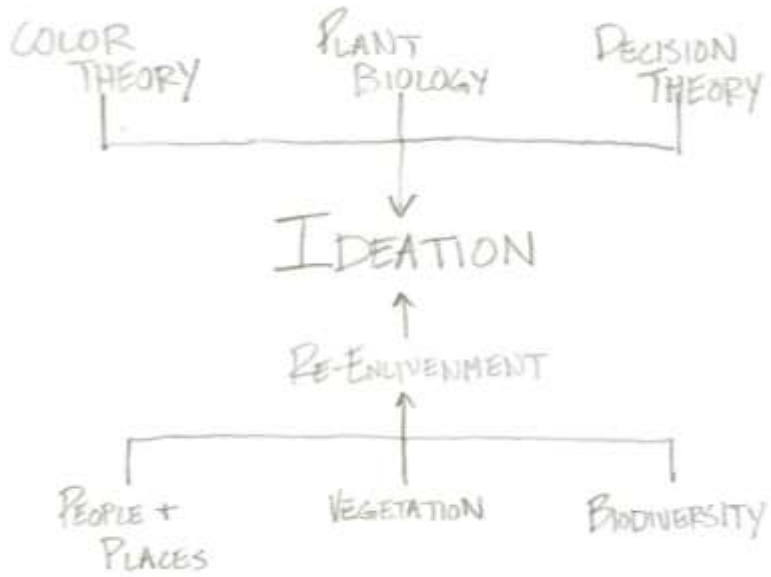

Figure 38: Inputs to Ideation for Dissertation

Though much of architectural research focuses on the physical outcomes of design, research on the process of design and the practices of both students in academe and professionals in firms is just as crucial. This philosophical method stems from three beliefs. First, the re-enlivenment of people and places, that there is a need for the inclusion of vegetated walls for the re-enlivenment in the built environment. Second, that then teaching and allowing interaction with vegetated and living walls enhances human life. Third, that the topic of inquiry is the built environment which enhances human life through biodiversity or biomimicry from the designs of the analyst/designer/researcher. This is done through a personal, phenomenological lens, that the designs iterated are based on past experiences. This process of ideation, representation and then iteration, through experience is supported by a mixture of qualitative and quantitative research using case study verification and experiential learning. The question being: how can a prototypical tool represent this through plant biology, color theory via decision theory? This allows for the systematic, but not necessarily linear, process of interaction and iteration which comes to an understanding and directed creation of knowledge.

Decision Support Structure: Triangulation

Triangulation is the method of supporting the inclusion of muliple methods to confirm the validity of assumptions made in the usefulness or efficacy of the tool. For example, by combining the work of previous decision frameworks by Dr. Elizabeth Grant and tool prototyping by Dr. Kongkun Charoenvisal, a

prototype and its decision framework can be made and then verified through studio work, an immersive case study in the form of full scale construction, and member checking. Each of these three paths overlap each other and check for inconsistentcies in the performance of the prototype tool or the methods in which to teach it to others.

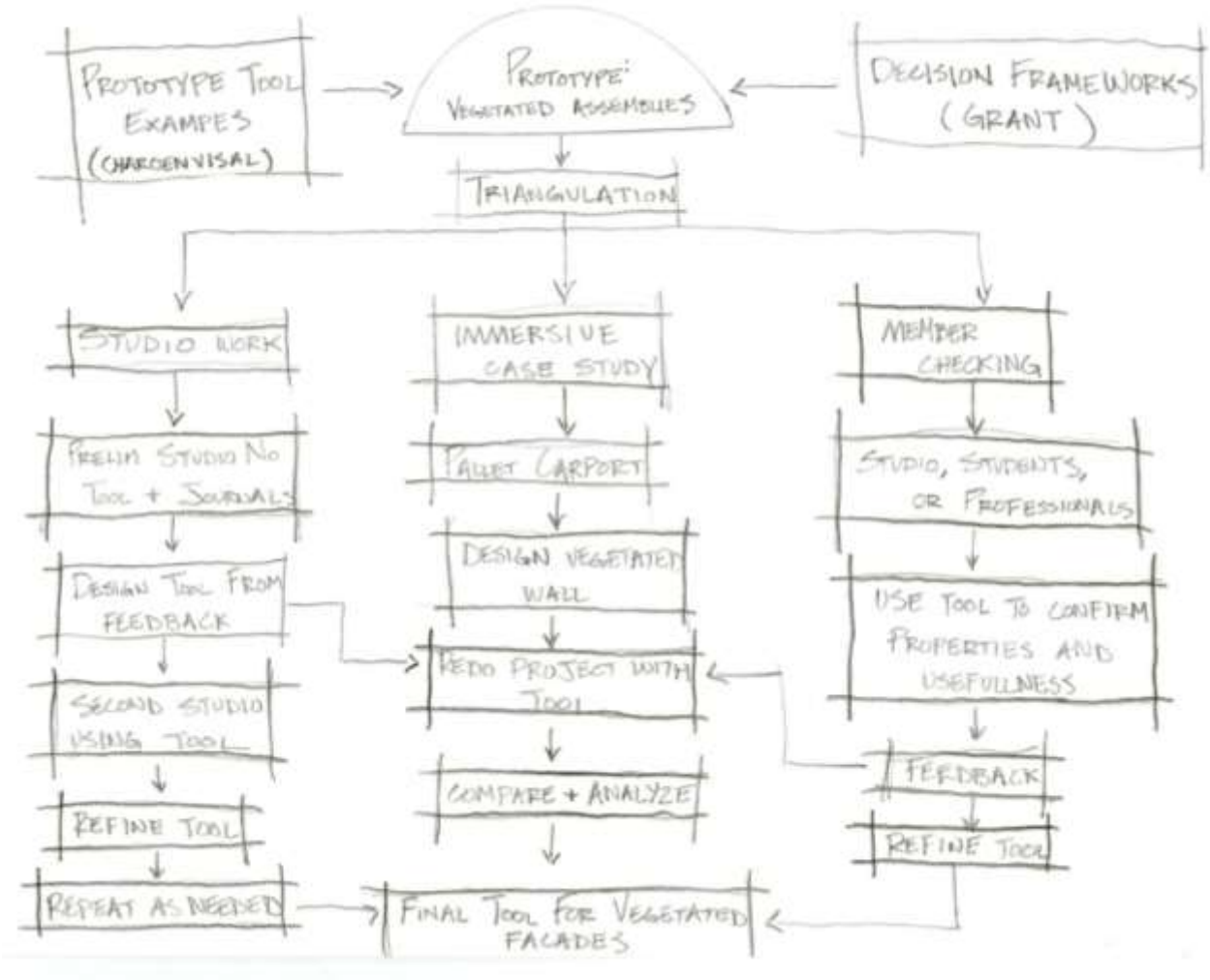

Figure 39: Triangulation of Previous theories to the prototype tool

Design Support Structure: a Prototype Tool

A Design support structure is created and maintained by decision theory. This theory is the method for how decisions are made, in what order, and which take precedence over which at each given point in the process. The general concept is that the inputs of color theory, plant biology and design tactics, such as materials or clinging mechanisms will be used to provide a framework to compare to the previous work by Dr. Elizabeth Grant and Dr. Charoenvisal.

The first step is to detail the work and find all of the parts and pieces to developing the framework and the resulting prototype tool in theory as well as the methods in representation that will occur in the tool as a part of a larger design process in the main project.

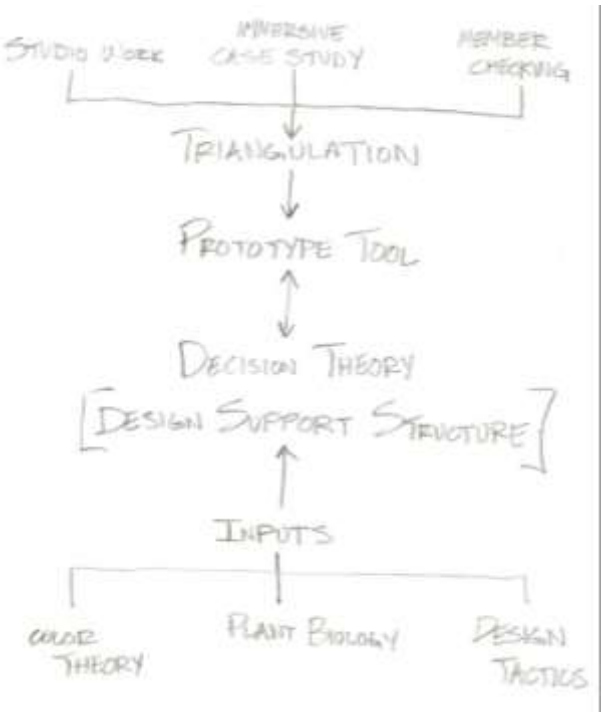

Figure 40: Decision Theory in reference to decision support for vegetated assemblies

The tool needs a framework in order to not only develop the tool but also to use as a guideline for when users are trying to implement the tool in the design process. This framework is different from a decision making framework which defines a decision, this framework informs the designer within a set of chosen criteria in relation to a larger design project at hand. This frame work has two parallel tracks, the first is the method of how the system will be framed and the other is the actual gathering of data in respect to color theory, plant biology, and design tactic (structure, materials, and attachment mechanism). Depending on the situation there are other factors: design methods (hand-drawn or computer-aided) and purpose (decorative or performance). Adapting the framework system developed by Thomas Jewel (Jewel, 1986) found in the work of Dr. Grant (Grant, 2007), we find that the framework for the vegetated walls can be incorporated in a more specific manner as compared to the general design framework he employed. Grant explains that these projects within the framework are often open-ended, or ‘wicked problems’ as explained by Nigel Cross. As projects use the design support structure they will evolve as data and criteria become more defined. Once again, this supports the fact that the design support structure and later the prototype tool are both a part of the design process, but not a replacement for the decisions of the designer. This tool is simply that: a tool, not a replacement for the designer. These two tracks of the system framework and data analysis are explained graphically in the following figure.

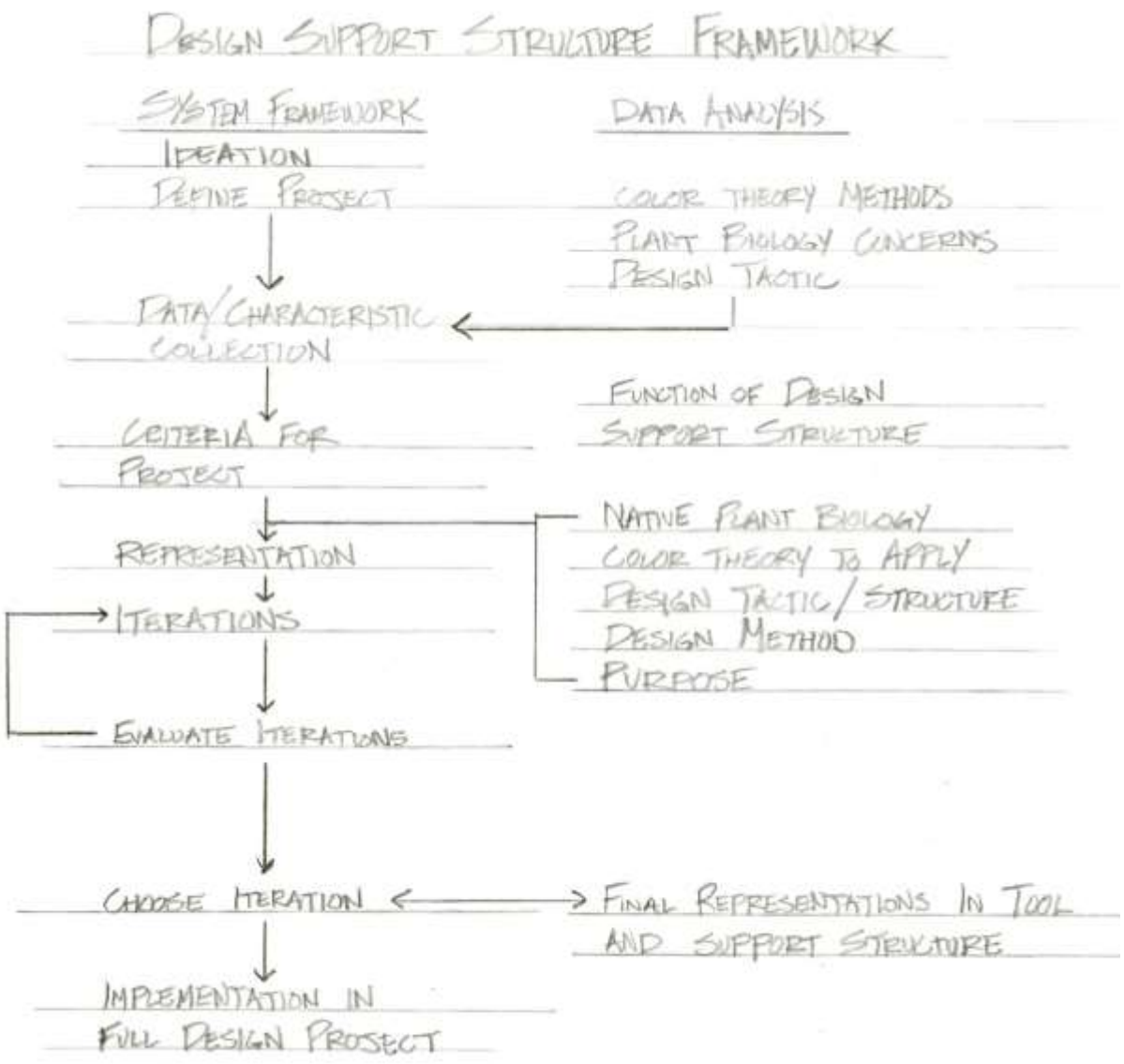

Figure 41: Full design support structure framework

The framework continues to use the main topics found in design of ideation, representation and iteration to inform the use of the tool and its criteria. This framework shows the five main aspects to the development of vegetated assemblies in relation to color theory. These five aspects or criteria have been explained extensively in the literature review in Chapter 2. These five main aspects are native plant biology, color theory, design tactic, design method, and purpose. The graphic on the following page shows how each with further explanation, relates to the subtopics that are present in each major criterion.

FRAMEWORK CRITERIA FOR USE IN PROTOTYPE TOOL

COLOR THEORY	PLANT BIOLOGY	DESIGN TACTIC	DESIGN METHOD	PURPOSE
COLOR	NATIVE TO ZONE	STRUCTURE	DRAWN OR CAD	DECORATION OR PERFORMANCE
IDENTIFICATION OF COLOR	METHOD OF ATTACHING	MATERIALS	INPUTS FOR TOOL	
DEPTH OF VALUES	COLOR OVER YEAR	SPECIES USED		
FIELDS OF COLOR USE	INDUSTRY USAGE			
METHOD OF REPRESENTATION				
COLOR MIXING				

Figure 42: Framework criteria for use in the prototype tool in relation to the design support structure

Referring back to figure 41, we have reviewed the inputs for the prototype tool, and need to explain the different verifying mechanisms that will serve as the triangulation for the tool, as well as serve as inputs for refining the tool as shown in figure 40. The first is a full-scale immersive case study, which is an electric car changing station or carport with a vegetated wall. The second is the development of a studio and curriculum to see the current methods of designing vegetated assemblies and then later in another studio to teach the tool and vegetated assemblies to students. The third is to then have a series of 'experts' evaluate the tool and see if it would be useful in designing such structures either in academia or professionally.

This panel of experts, termed a Delphi, will then inform the use of the tool in the studio, as well as the work with the carport. It is important to understand that this process of triangulation not only verifies the prototype tool and its framework, but also the triad of the immersive case study, the studio and the Delphi.

An Electric Car Charging Station and a Vegetated Wall

The electric car garage and its associated vegetated wall are the first step into understanding vegetated and living walls. A qualitative study will be conducted using the species for visual effects on the Electric Car Charging Station that was constructed for the Electrical and Computer Engineering Department at Virginia Tech. This structure was built next to one of the previous Solar Houses at the Research and Demonstration Facility at near Blacksburg. This project will serve as a basis for calibrating the representational style of the prototype tool in reference to an existing structure. By following the entire process of the design, construction, implementation, growth and evaluation of the electric car charging station and its vegetated facades, a more accurate model can be produced to represent other future structures.

A Qualitative Study of Vegetated Facades on a Charging Station

The Electric Car Charging Station will be constructed to be used in part as a platform for the qualitative assessment of the attached vegetated façade system. A more detailed description of the construction process used in building the Electric Car Charging Station and the vegetated system will be provided later in Appendix A. The vegetated system has two plot segments, both four feet wide and approximately eight and twelve feet tall. Each will be planted with Virginia Creeper**.** Over time the plants that grow on the vegetated façade structure will be documented.

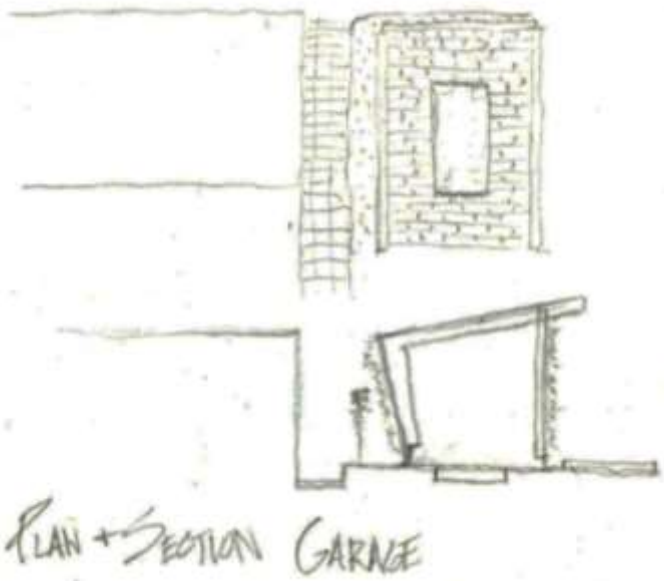

Figure 43: Initial Plan and Section of the Carport

Figure 44: Carport under construction

The vegetated assembly will be a simpler design, using stained dimensional two by sectional lumber, and a wire mesh or wood lattice supported by intermediary blocking, so that the wire does not sag over the distance. The vines, either twining or holdfast, would then be trained onto the wall system. Next, the two plants will be installed at the base of each plot directly into the ground. This will make both sections vegetated facades by definition. The plants will be monitored and cared for closely during the beginning of the plants' establishment using water and fertilizer to ensure their survival. Since the study is qualitative and not quantitative, the adjacent plots will be allowed to grow into each other, and vine re-direction will be done to help coverage remain only on the constructed vegetated façade and not the main structure.

Virginia Creeper does have drawbacks, many of which are due to its vigorous growth. This growth is able to choke out other plants such as trees and shrubs. However it is this same quality that allows it to be used as a groundcover. This same quality will allow Virginia Creeper to be used as an excellent wall cover on the north side of the electric car garage. It has the potential over time to cover the wall completely and will need to be maintained as to not let it cover the entire structure, unless desired. If total

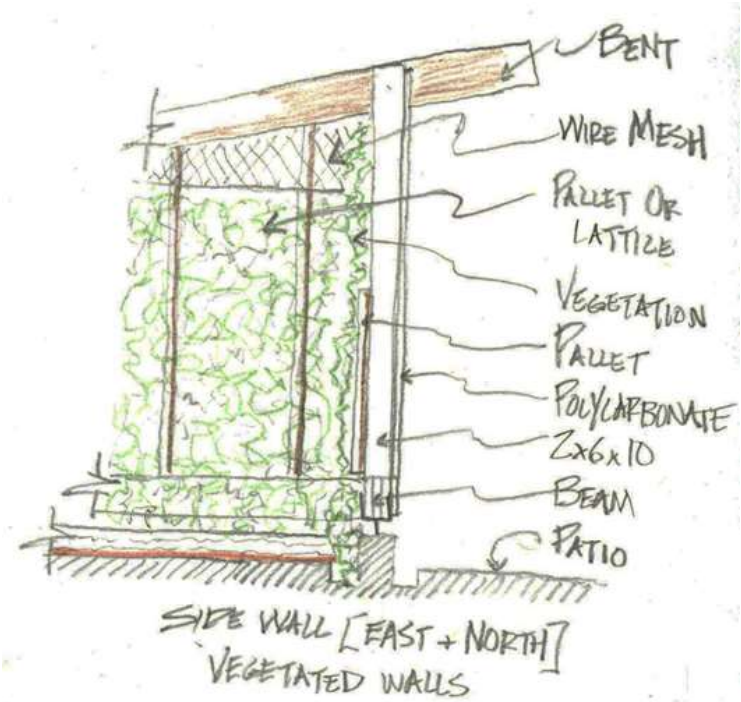

Figure 45: Sketch of the Vegetated Wall for the Carport

coverage were desired, the structure has been designed to take the extra weight of the growth over time.

Documentation of the growth of the planted Virginia Creeper will be regular over the course of at least one growing cycle (one year). Pictures will be taken once a week both in the morning, afternoon and evening for growth and lighting conditions (sunny and cloudy). This will allow for different lighting conditions and a review of how light affects the appearance of the plants. These photographs will also be taken over the different season to be able to see how the different plots behave and appear during the seasons and varying conditions, with a grid placed over the image to compare growth. A photograph will be taken from the interior and exterior of the vegetated façade. Overall six photographs will be taken at each event or week.

During the photographing period, the characteristics that will be used for reviewing the morphology and physiology of the plants for the purpose of color theory in the study include: texture (fine, medium, bold – may be one texture during growing season and another in winter), foliage size, color, and shape, and dormant season appearance, and flower and fruit [conspicuous or inconspicuous, size, color; month(s) of appearance]. Most of these characteristics can be found in the NRCS plants database. The characteristics found on the vegetated wall of the electric car garage will be compared to the characteristics listed in the database to understand development as well as final appearance. These characteristics will be reviewed over time to see how they develop in a vegetated façade situation, along with anything interested during development. This concurrent study of the vegetated wall will be conducted with the intent to use the information gathered to assist in the development of a prototype tool for representing vegetated facades. By using some of the characteristics outlined by the photographic studies in the proposed research project and simulation reproductions, the decisions made in the vegetated façade of the electric car garage will test some of the tenets of color theory as applied to vegetated walls. An example note sheet is included for reference as follows.

Observation of the Electric Car Garage Note Sheet

Table 4: Note Sheet

	Date	Morning	Afternoon	Evening
Plant Color				
Density				
Coverage				
Flowering				
Fruit				
Lighting Condition				
Percent Cover				
Other Notes:				

Reviewing the Electric Car Carport Design and Construction Process

This garage's vegetated wall will provide a base for further study via continued monitoring. The computer simulations of possible designs, developed from the photographs, will show the potential characteristics amassed in the study as they are applied to architecture. By using these initial data gathering and color study, a later decision support structure (DSS) such as the prototypical tool for the representation of vegetated assemblies can show designers a beginning point when using vegetated facades in architecture.

This project will also serve as a learning experience in organizing students to complete a full-scale constructive task. The project then is a learning experience for both me, as a researcher and organizer, and for the students would will assist in the project. The garage is an adaptation of previous undergraduate thesis work, bridging the work done then and the current research on vegetated living walls. The purpose being to see how reclaimed materials and structural design influence a built environment and vegetated walls based on a repeated module of a pallet.

Since the intention of the project is to not only build the final designed structure, but to also use the garage for an electric car, many disciplines could be included in the project. Some of the disciplines would fall within the college of architecture and urban studies, but other disciplines outside the college have areas of expertise that are useful and helpful to the project. These disciplines are in no hierarchical order when in a design or project situation and the group's success is dependent on the cohesion between individuals.

While there is a set goal of constructing the electric car garage, there is a multitude of information and projects such as this which are open-ended and meant to challenge design teams. The goal of the project is to have students explore how to become critically engaged, internally and externally reflective collaborators in their own designed responses and how to maintain a positive work environment. The students also will begin to understand collaboration as the facilitator for life-long learning in their discipline and acquire the necessary skills to represent and discuss personal and colleague projects, moving toward and creating a personalized professional style. The students will also gain insight and exposure to the professional styles of other disciplines and be able to incorporate useful techniques unto themselves.

Finally, the students will gain an understanding of how to present collaborative work to donors or other interested individuals.

The team could be assembled via a designated class, or through self-organization. For this project it was originally done through self-organization with some members joining later through a class. Then, developing the design solution was done by performing extensive background research of the problem and potential solution alternatives. The team compiled this information into a preliminary conceptual solution, which was presented to the stakeholders to solicit their comments. For this project the Electrical and Computer Engineering department at Virginia Tech was the client.

Once feedback from ECE was received, concerns regarding conceptual design were addressed in a revised solution. The revised solution was developed and presented as a final design/solution to the problem for construction in 2013 with the original four group members, most of who have graduated. The final design should include any plans, specifications, reports, approval applications and presentations needed for a project of this. All of this information will be compiled in a professional quality, organized project book by the researcher and the current group of student workers. The final representations and project book will be presented to the stakeholders, accompanied by a thorough presentation that clearly demonstrates how the final proposed design accounts for their concerns and solves the problems. Depending on available resources then project could then be constructed. This is the same process as the process that will be used for compiling work in the studio books for the prototype tool for the vegetated walls. This doubling of experiential learning allows for students to take personal experiences and use them in their design method and work.

The team will gain a more holistic view of how the problem crosses many different disciplines and how such disciplines play an important role in solving the design or problem at hand, as well as develop a solution to the design programme and program that explains in detail the implications and consequences of such a conclusion with outside support. These lessons will be used later to help develop the vegetated and living wall designs in the larger and later of the representational tool. By taking this multidisciplinary problem-based project, students will have a basic understanding of how to navigate objectively through a problem and address any subsequent problems caused by its development. I as well as team members should be able to research a situation from multiple viewpoints and compile many sources and derive a

consensus design solution. Afterwards we will be able to present the plan and solution. The critical realization will be to understand group work and the balance between individual effort and group effort on a project and how research influences design from ideation, to representation, to iteration, and to implementation. Finally, it is important to understand that research can and should inform the design of a project, that design is not a discrete event, but a continuum, that the past can influence the present designs and that the present course can shape future endeavors.

Presenting the As-Is studio method to Vegetated Assemblies

Analog and Digital Representation

While continuing to monitor and catalog the growth of the vegetated assemblies, the next phase of the study will be to devise both an analog drawing method using the hand and a digital prototype tool representation method using Google SketchUp, and Rhinoceros with Grasshopper. The main focus is not to determine for the students what method should be used, but be able to help students in the method that they choose in the beginning when trying to represent design projects and vegetated or living walls. For example, by having knowledge of watercolor and mixed media the professor can direct students in a knowledgeable manner, or direct those to someone who can help them even more. The main purpose is to facilitate the ability of the student to learn and develop as a future professional.

When using hand drawings and hand modeling, a student's specific representation style is embedded in the work. The stroke of every line reveals an architect's mindset and care in their craft. The purpose of the professor is to guide the further development of this work and its potential. The same can be said for computer programs. These programs serve the student in a similar manner to the hand. Each drawing and representation is unique to the student; however it is from the digital realm. This digital style can make it more difficult to see individual differences when using similar programs. For this reason the types of software used in the studio are common, but easy to learn. Google SketchUp is free software for download, but has the least amount of detail and features. Grasshopper is tied into software called Rhinoceros, which is a 3-Dimensional modeling software mainly used in academia, and less in the professional arena.

The goal is to have student work with an easy to learn or familiar software with a minimal learning curve; however the final products from it are of very high quality. Each student will get a different project, similar to the thesis 5th year at Virginia Tech that they will develop with a core question. The purpose of this is to help the student prepare not only a representation style, but also for the different nature of the thesis year and to test out thesis ideas beforehand. While the students develop their own drawings, I will work with them using the electric car charging station as a reference for the representation process in all of the different programs. By having a visual reference as an impetus for exploration, the students can more effectively develop their own methods of representation.

Architectural design is inherently a decision-making process of which the making of new ideas (ideation) and representation are at its foundation. Designers typically move from ideation to representation and then to multiple versions of a design (iteration). Moving from the more abstract step of ideation, representation allows the architect to move from an idea to issues of quality of space, materials, construction, or in this case color theory and vegetated assemblies. With the continued and increasing use of computers for design, digital representation, and simulation, ensuring the design process does not become prescriptive, formulaic and driven by the computer, is critical. When students are given the choice, will their method of representation be by hand, digital, or both? Technology has given students many opportunities and methods to design that simply were not available until recently, for example Photoshop, which is a flat rasterize program; and Grasshopper, a Rhinoceros plug-in, and Google SketchUp. At Virginia Tech, a group of students were given a two week project in the 2nd Year studio with the criteria to use vegetated assemblies. Their work was reviewed in relation to what types of design representation and methods were chosen and used by the students in support of their design decision making.

From this study a prototyping tool, or design support structure will be designed. This representational tool will serve as an outlet, an extension of the representational process, allowing for a design in its totality, not simply the ideal conditions. The representational tool will allow designers to test their proposals to better understand their implications and allow clients to visualize a vegetated façade over a range of conditions.

The purpose of the current study is to see not only what do the students design when using vegetated assemblies, but how and what tools or technology they chose to represent their ideas and help make decisions. This is to determine whether or not the targeted programs for the representational tool to accept 3D models for representation are in fact the programs students use. The tool would help inform the designer, but not make the decision for them. This research has at its foundation the evolution of iteration and representation, trying multiple avenues and confirming assumptions, which is a core process in a studio. This so that the programs can be determined accurately for the larger study which is aimed at changing the way buildings are designed by creating a prototypical tool for the representation of vegetated assemblies, in this instance vegetated walls and facades and how they relate to color theory. The future tool would accept a 3D model or photograph as input and then re-represent the elevation with the selected plants. These students and this study provide the foundation for that research.

Current As-is Methods for presenting Vegetated Assemblies

The current steps in architectural design typically follow these steps, they inform each other, but proceed generally linear in manner to deliver a set of drawings to the client. The steps are: Site analysis, pre-design or schematic design, design development, construction documents or contract documentation, negotiation and bidding, then finally construction and contract administration. This process then culminates in as-built drawings. Teaching and studios in academia are focused on the pre-design/site analysis, schematic design, and design development, and rarely make it to the construction document phase.

In a studio, a prompt or brief is given to the students, and is used as the basis for design. This brief typically has base parameters for the project, its location, and any central themes that might be suggested to explore in the design process. The students then might visit the site to do site analysis and sketch out preliminary designs in a sketchbook. Then they might begin to represent these ideas in more refined representation at scale, but not typically in the rigid method of construction documents. Often these designs are drawings that resemble plans, section, elevation, axonometric, renderings or perspectives. Then these will be reviewed in presentations where the students share their work with the class, professor and possible interested third parties. Typically these presentations would happen more

than once over the semester to discuss progress and other ideas that could refine the process. The core theme is that these projects might be completed for the purpose of the studio, but a meant to serve as a continuous process in exploring design to develop a personal or specific architecture for each student. This is not always the case as some schools have developed a master-apprentice method in which the students begin to mimic the methods used by the master. For the purpose of the this study, the methods employed will be those by the Virginia Tech teaching body as they are less restrictive and allow for a wider range of design styles and representations. The diagram below shows the current methods that are typically used in a studio, and the areas where the tool could serve the greatest help of use.

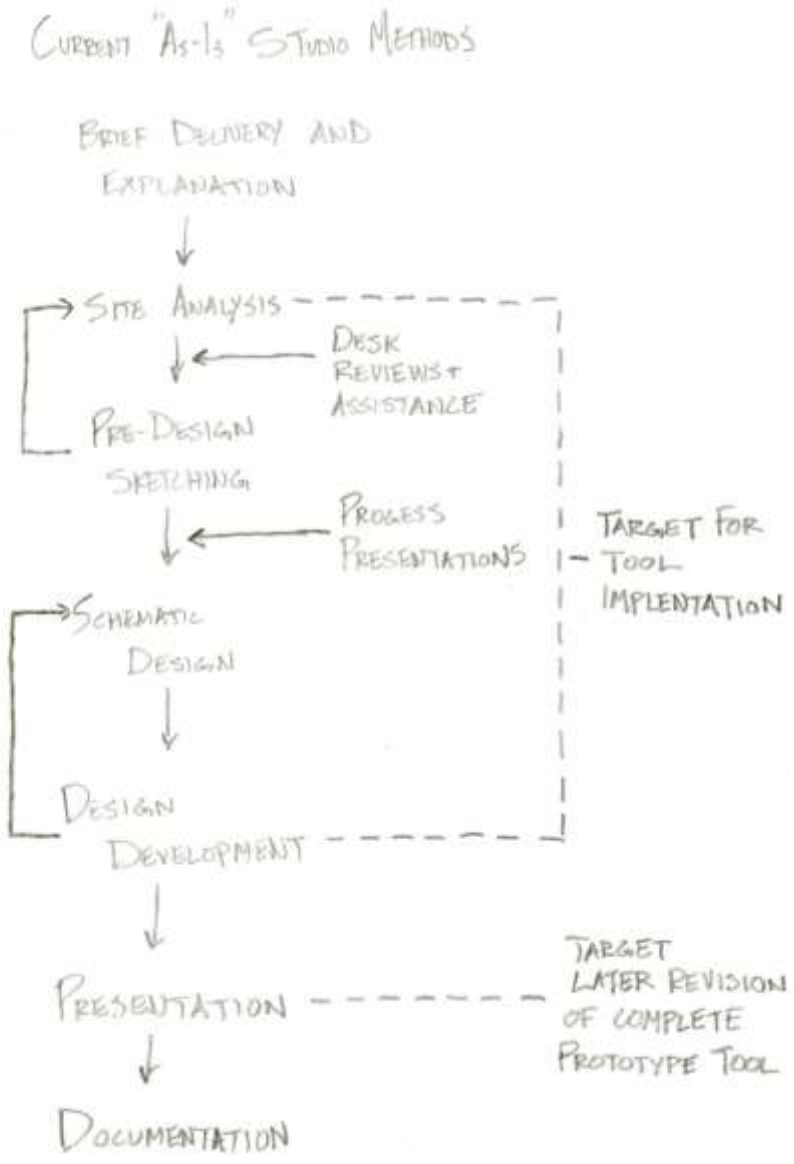

Figure 46: Current As-Is process for implementation of the prototype tool

Using Vegetated Assemblies in the As-Is structure?

In Mario Cortes' laboratory, before the specific project on vegetated assemblies was introduced, the students had already begun to incorporate them into designs and show ways of representing vegetation on walls and roofs. This implementation of vegetated assemblies was on their own, with assistance from technical books. These project in figure 48 reveals that vegetated assemblies are still viewed as add-ons, without understanding the impact such assemblies can have on occupants or the structure. This is not a negative situation; in fact, it shows that students are interested in the potential these vegetated assemblies can bring to the design. These models show that students are more aware of vegetated roofs as a type of vegetated assemblies. Two different materials were used: modeling moss and green mat-board. The mat-board suggests that the vegetated roof is uniform in color, height and texture, while the modeling moss shows an indication of depth and shadow, but is still uniform in color and plant species. This is very common for the first time a student uses a vegetated roof, that it, in their mind, should be grass on the roof of a building. In the very beginning of vegetated roofs this was the case; however specialized types of soils and plants are now designed for the roof conditions. These are the very first steps towards a greater understanding of vegetated assemblies and their uses and representation. Unfortunately the students did not have two-dimensional representations of the green roofs, either hand-drawn or digitally generated. This suggests that the vegetated roofs were a discovery during the model-making process. The models students make are process-driven and not intended to be final presentations of the design.

Figure 47: Vegetated Roof on a lookout

Other examples of vegetated assemblies in design involve preliminary sketches and design development before final representation. The images on the following page show how sketches can encapsulate an idea and serve as the impetus for the use of vegetated assemblies in a project and how there is the potential for a tool to show designers how such assemblies could be used in the larger context of a design project as shown in figure 47.

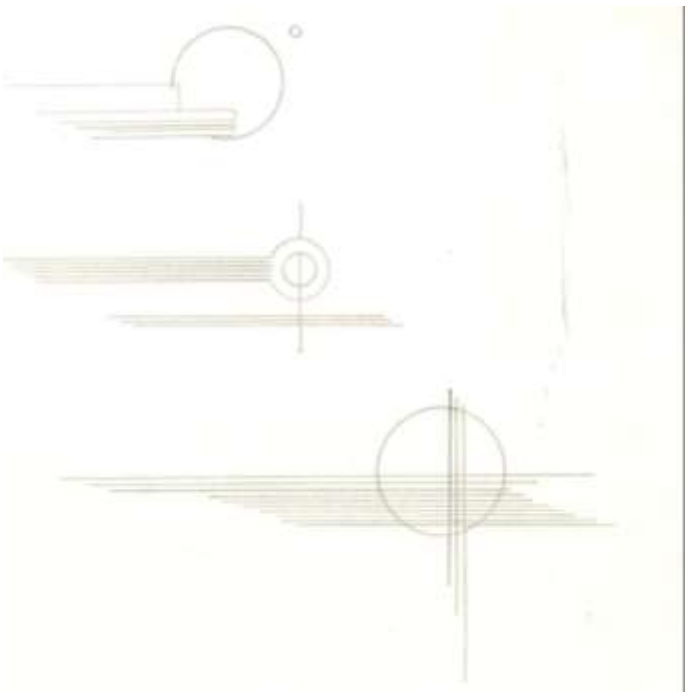

Figure 48: Geometric abstraction of plan and vegetation proportioning

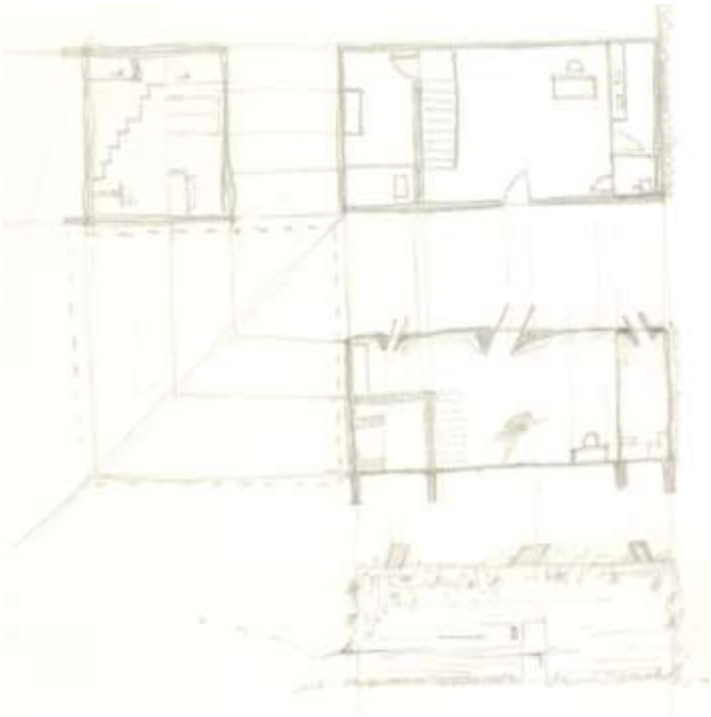

Figure 49: Plan, section, elevation, in relation to direct applied vegetation

All of these examples are hand-drawn examples of how vegetation can be brought into the pre-design sketches and into the site analysis portion of the current As-is process in the design studios. These first two sketches are two different sets of pre-design sketches. In this phase, generalized ideas are being sought.

For example in figure 49, there is a more pure geometric exploration of the possible plans and vegetation proportioning for a vegetated roof. The first shows the vegetation piercing into the circular plan, the second shows a single path connecting the plan with an attached set of roofs, and the final one shows the two levels of vegetation intersecting over the circular plan. In this phase, the program and the brief are still independent of the sketches. The sketches are exploring the potential of future layouts and designs.

In figure 50, the vegetation is explored through more recognizable plans, sections and elevations, exploring how the vegetation might be used as a facade cover on a modular studio structure. This is an example of how vegetated facades can be engaged in the schematic design phase before moving into full representation of ideas.

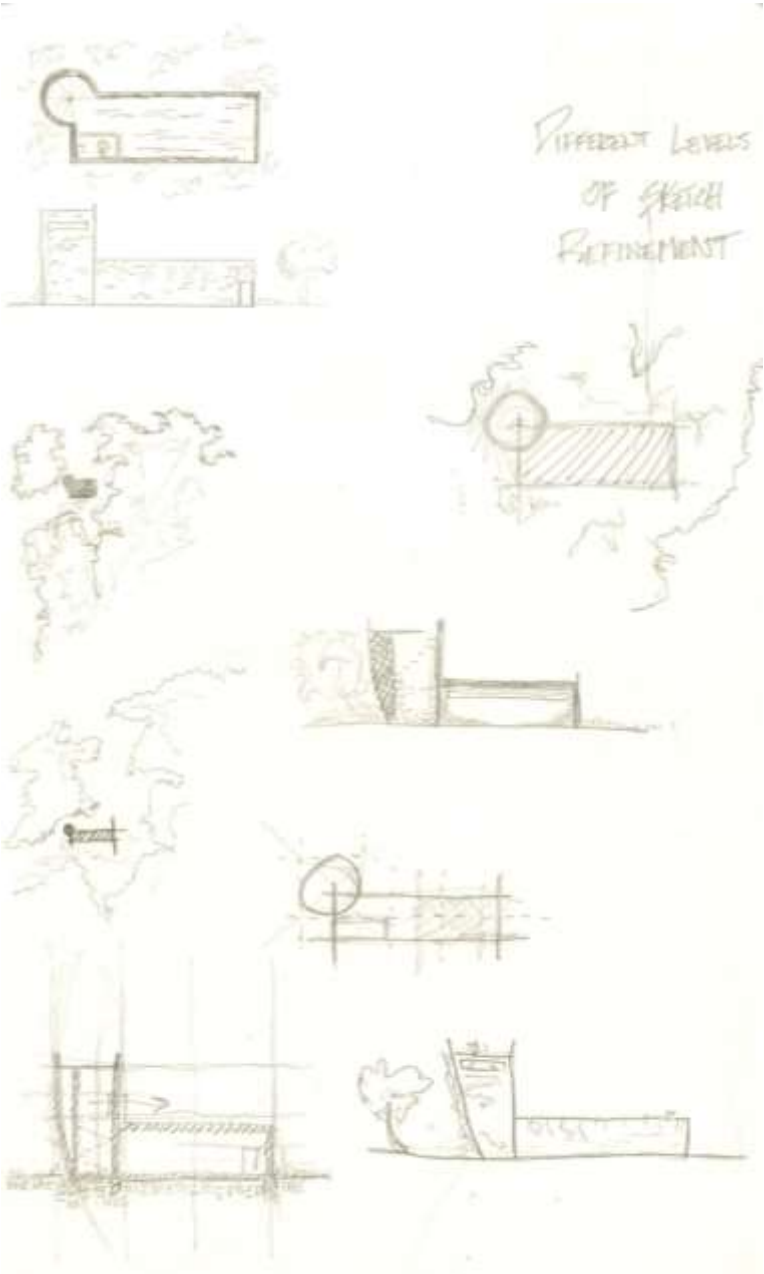

Figure 50: Set of sketches in predesign exploring how to implement vegetation

Figure 51 is also showing an example of the schematic design phase, but at different scales and reviewing how the project will sit on the site. This shows how the initial site analysis can influence the later stages of design. For example there are rough parti sketches and site plans, as well as diagramatic sections that can heavily influence the use of vegetation on the façade if used in conjunction with the prototype tool in the future. By mixing the propotioning system that the student designs, the prototype tool can show different methods of how the façade could look with the inclusion of a vegetated system, its materials, and the design tactics used.

All of these sketches show that the design process, while it can be represented in a linear fashion, is actually a more recursive process, with steps in design all influencing each other in an iterative process. Therefore it will be important to target the pre-design and schematic design portions of the As-is design process to have the prototype tool be the most useful for the students. It is in this portion of the process that the tool can be used to explore ideas, rather than be used as a final representation or rendering. It will be very important to see how the inclusion of the tool influences the design process, but does not become overbearing.

Introducing a Studio Prompt to determine As-Is structures: Two weeks and beyond

This As-Is process is the method of designing and teaching currently in the studio environment. This process will be applied to earlier work and the short, two-week project with second-year students will gain insight for the first larger and longer studio or focus class that would review current techniques in more experienced students, most likely fourth-year students, to determine how designers (students) currently would address the process of representation and decision-making as it related to vegetated assemblies. Afterwards a second studio or focus class with fourth-year students would be implemented with students would include the use of the prototype tool and the development of a new studio. This whole process could take anywhere from one to two years, starting as soon as the spring of 2015. By determining and presenting the As-is situation as compared to the new frameworks, it helps structure the findings and discussion for the tool, its use, and its representations.

This first project will use the teaching method of the second year studio and the two-week project module to determine how students will interact with a project based on previous experiences. By using a series of two-week projects, students will be in an iterative mindset, and be able to make decisions about projects quickly, using the constraints provided by the brief and site efficiently. This project will also be a learning experience for me, to learn how to lead a studio without support. It is important to take out the uncertainty of teaching experience as much as possible to limit its effect on the students during later and larger implementations of the new studio frameworks and the use and revisions of the prototype tool. Following is the studio prompt for the two-week project involving an amphitheater near the Duckpond on Virginia Tech's campus. The project is designed to get the students thinking about a larger site context than a singular location and the implementation of vegetated facades.

In summary this two week project will serve as the basis for the entire study in relation to triangulation and what methods to implement in the prototype tool. This is founded on that architectural design is inherently a decision-making process, and the making of new ideas (ideation) and representation are at its foundation. Designers typically move from ideation to representation and then to multiple versions of a design (iteration). Progressing from the more abstract step of ideation, representation allows the architect to move from an idea to issues of quality of space, materials, construction, and, in the case of this investigation, color theory and vegetated assemblies.

Therefore, with the continued and increasing use of computers for design, digital representation, and simulation, ensuring the design process does not become prescriptive, formulaic, and driven by the computer is critical. When students are given the choice, will their method of representation be by hand, digital, or both? Technology has given students many opportunities and methods to design that simply were not available until recently, for example, Adobe Photoshop, which is a two dimensional graphic editor program; Grasshopper, which is a Rhinoceros plug-in; and Google SketchUp.

In this preliminary study, a group of students were given a two-week project in the second year studio with the requirement to use vegetated assemblies. Their work was reviewed in relation to what types of design representation and methods were chosen and used by the students in support of their design decision making. From this study a prototyping tool, or design support structure, will be designed. This representational tool will serve as an extension of the representational process. The representational tool will allow designers to test their proposals to better understand their implications and allow clients to visualize a vegetated façade over a range of conditions.

The purpose of the current study is to see not only what the students design when using vegetated assemblies, but how they design, and what tools or technologies they choose to represent their ideas and to help them make decisions. This is done to determine whether or not the targeted programs anticipated to accept 3D models in the representational tool are in fact the programs students use. The envisioned tool will help inform designers, but not make decisions for them. This research has at its foundation the evolution of iteration and representation, trying multiple avenues and confirming assumptions, which is a core process in the studio.

Studio Project Prompt

ARCH 2015
Focus Project: The Choreography of a Living Wall:
A Living Wall for President Sands

Fall 2014
Instructor: Kenneth Black
400X Cowgill Hall
kenblack@vt.edu

This project seeks to explore the boundaries between nature and its application in architecture. This project will serve as an exploration into what a vegetated wall can be when designing an amphitheater at Virginia Tech in the context of a specific site.

The project is located near the president's house up the hill from the duck pond, across the road from Hillcrest Hall on the site of the old WPA amphitheater. In the project it would be ideal to be able to explain its sense of place, so please visit the site when reacting to its conditions. It is under the tree cover inside the red box in the image. This project has the opportunity to serve as a place to entertain and showcase performance arts such as theatre and cinema. Treat the project as an extension of the surrounding area, including the President's ability to entertain guests.

The important things to consider are issues of sustainability, vegetated walls, and water recycling for the living wall and amphitheater intervention. The project interventions can be made of any materials.

Finally, each student will also maintain a work journal that describes their process and evaluation of the studio and professor (Ken). This is essentially a word document that shows what you did each day, how you did it, and your thoughts on the teaching method (expectations and results). Please keep track of all you work as you will need to turn in a digital copy of the work in the form of a portfolio presented at the end of the project period.

Program:

2 Bathrooms:	120ft^2
Box Seat Area	400ft^2
Covered General Seating	300ft^2
Uncovered General Seating	700ft^2
Vegetated Wall	300ft^2 Vertical wall coverage
Covered Stage	350ft^2
Storage	75ft^2

Method review for Implementation: Interpretivism and Tactics

The work from the first project in the studio will inform the method of teaching and the method for the prototype design tool in the second studio. The content from the journals and the books of the first studio will be critical in understanding, evaluating, and then improving the design methods and tools that can be employed by students and professionals. The process for reviewing the journals and books includes a combination of interpretivism and logical argumentation.

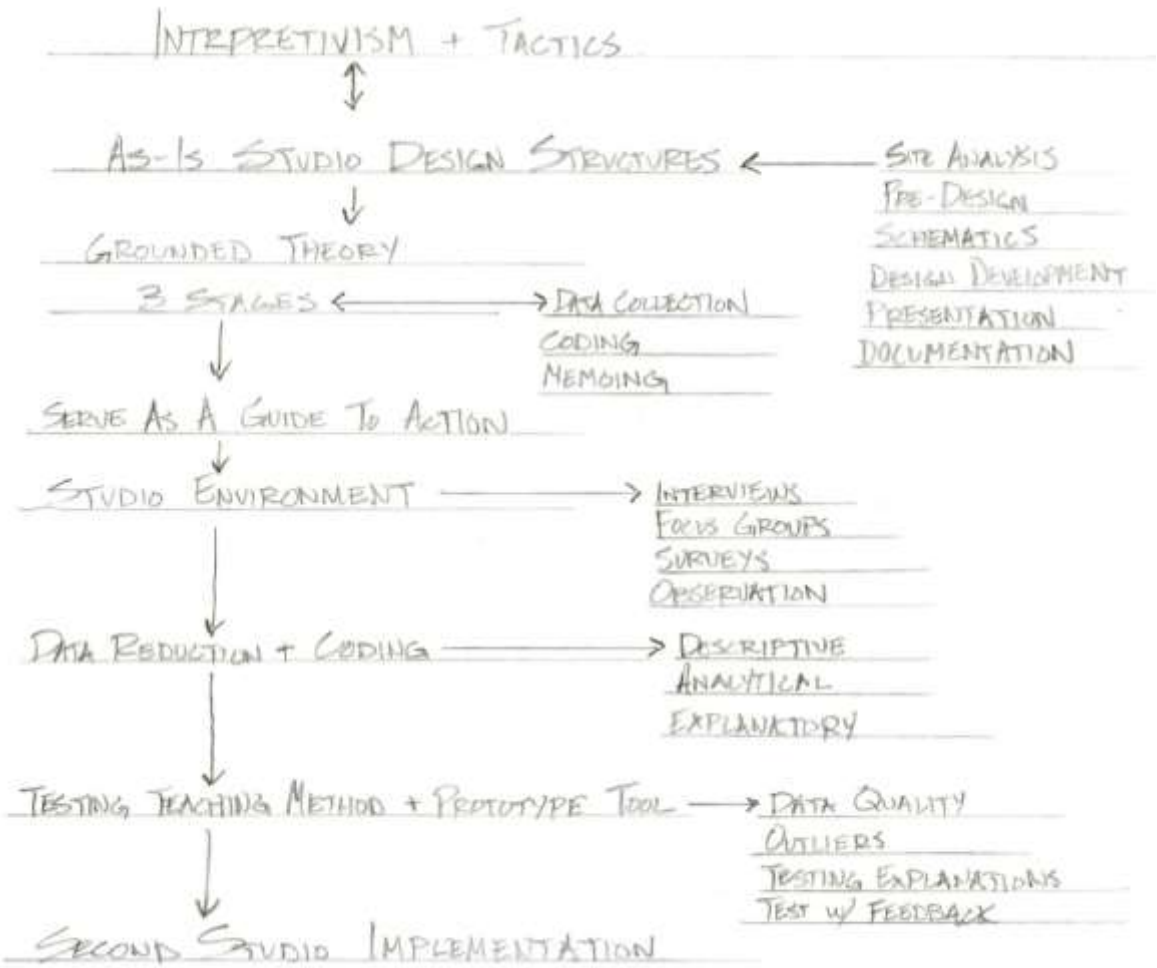

Figure 51: Mapping of Interpretivism and Tactics for use in evaluating As-is structures and future frameworks

This combination of methods, after reading the entire written content first will allow for the defining of the criteria (reasons) for selection or categorization. This process is in the nature of grounded theory (Glaser & Strauss, 1968), as explained by Strauss and Corbin in Groat and Wang:

> In this method, data collection, analysis, and eventual theory stand in close relationship to one another. A researcher does not begin a project with a preconceived theory in mind (unless his or her purpose is to extend existing theory). Rather the researcher begins with an area of study and allows the theory to emerge from the data. … Grounded theories, because they are drawn from the data, are likely to offer insight, enhance understanding, and provide a meaningful guide to action (Groat & Wang, 2002).

This process uses three stages: data collection, coding, and memoing. What is interesting is that the stages are not complete at any time and can be returned to as new information arises or new data is collected and reviewed by the researcher. As with design, this is an open and iterative process to develop a theory.

Interpretivism, as described by Thomas Schwandt in Groat and Wang, is the attempt to resolve "the paradox of how to develop objective interpretive science of subjective human experience" (Schwandt, 1997). To interpret something correctly, context must be given to not only what is observed, but the observer as well, thus the phenomenological nature is still key to Interpretivism. As Schwandt explains, "the inquirer constructs a reading of the meaning making process of the people he or she studies" (Groat & Wang, 2002; Schwandt, 1997). With the journals and the books, much of the content will need to be interpreted in the context of the other journals, the studio, and the student.

When the students are interacting and working on the project and the journals, they should be working with the journal in a self-reflexive manner, rather than a simple chronology of event in the design. It would be better to have them understand and articulate the spirit of the project and their experience with it that there could be a unity of self and the educational and design environments. As Groat and Wang explain, "in studies of a phenomenological nature, such use of words may also be data" (Groat & Wang, 2002). It is not just the words that can come to express the phenomenological interaction student

have with the world, but also drawings and representations of architecture. When the journals and books are reviewed all of the content will be coded and analyzed, as designers express themselves more often in representation, rather than simply words.

There are a number of tactics that can be used to create different sets of data and then reduce this data and code it for use in memoing a theory. The table below reflects the data gathering stage of the prototype tool and method which in this case is a 4th year studio. These tables are based off of the tables presented in Groat and Wang from Miles and Huberman (Miles & Huberman, 1994):

Table 5: Tactics for Use in the Studio Environment

Tactics	Interactive Nature	Noninteractive Nature	Use In a Studio
Interviews	Personal Histories		"What is your personal architecture paper" Position Statement
Focus Groups	Discussions in small groups to test method Participants help construct questions		Studio Teaching Method Studio Presentations Student Journals
Surveys	Projective Surveys		Desk Crit
Observation	Student Observation	Notes of Behavior	Personal Journal Desk Crits Presentations
Artifacts		Interpretations	Books and Journals

The next stage is the data reduction and coding of what is gathered from the semester long studio study. Some of the data will be collected over the course of the semester and others will be garnered through the submittal of the final journals and project books. After this data is reduced, the coding method and final results will be presented in a large display for future review.

Table 6: Tactics for reducing Data and Coding to find Meaning in Journals and Books

Tactics		In Studio Method
Descriptive	Noting patterns and themes Seeing plausibility Clustering Making metaphors Counting	Midterm Presentations Final Presentations Desk Crits Personal Journals
Analytical	Making contrasts + comparisons Partitioning variables Subsuming particulars into generals Factoring Noting relations between variables Finding interviewing variables	Personal Statement Final Books Relations between student books
Explanatory	Building logical chain of evidence Making conceptual + theoretical sense	Books and Journals tested against the desired method

Table 7: Tactics for Testing the Teaching Method and Prototype Tool

Tactics		In Studio Method
Data Quality	Checking for representativeness Checking for researcher effects Triangulation Weighing the evidence	Multiple studios Multiple journals and books Multiple desk crits per student
Outliers	Checking the meaning of outliers Using extreme cases Following up surprises Looking for negative evidence	Comparing books and journals with positional statements Review preliminary books with student prior to final submission
Testing explanations	Making if-then tests Ruling out spurious relations Replicating a finding Checking out rival explanations	Cross examining all of the books and journals to each other to develop coherent methods and theories
Testing with feedback	Getting feedback from informants	Student review of teaching method in the journals

Using the position statements from the beginning of the semester, the researcher can look for consistent themes throughout the works, and find interesting information about the student's design process. From the journals and books there will also be the opportunity to test the method of implementing the studio and its environment. The hope is that the data that is reduced from the student's work will be organized through its interpretation, and then allow future studio successes to be predictable, using a verified prototype tool method and educational method that will still allow for the individual expression of each student designer.

These different tactics (table 7) for coding, reducing, memoing, and then verifying the studio process and the prototype tool are critical to complete before the implementation of the second studio. This process of coding and memoing will need to be duplicable if a third or more studios were to be implemented in succession. These studios will allow for the holistic approach of design to not be altered while trying to develop a more coherent method on design with vegetated assemblies.

Design cannot be done overnight, the flexibility that a semester long studio gives will be critical to developing of a working theory on teaching such methods to students. Also, this level of flexibility will allow for adjustments over the course of the study should new variables of interesting methods arise. Finally, the researcher needs to be sensitive to the artifacts that the students develop towards 'their own architecture' and the activities of the researcher do not impede the studio and allows proper development of designs and strategies. This method will create a large quantity of data and without a step-by-step procedure, the data cannot be used to its full potential. By participating or teaching a studio as completely as possible, with student life and design, a useful design tool and method can be developed.

Second Studio Concept

After using the coding, data reduction, and memoing method, the second studio will be a supporting step in verifying the teaching method used in the first studio. By reviewing what the students found to be useful or unnecessary, the methods of teaching, using the tenants from the studio conduct in the syllabus, both the teacher and the students can work together to create a positive and effective learning environment. Of course much of this will be determined at the time between the first and second studio. Much will remain the same, but tweaks will be made based on the results of the first

implementation of a studio. This process hinges on that fact that more experience in teaching and using the prototype tool should result in a more cohesive plan and teaching style for informing the students. This in turn should make the method and prototype tool more useful, or more easily understood.

This review of the first studio method in relation to the second studio method is how teachers can continue to have a learner-centered approach to teaching, configuring the studio and adapting it to the students' needs rather than for simple convenience of the teacher. This is why the procedure is to use the analysis from the first studio to inform the second. The same studio prompt as shown before will allow for whole a new set of ideas with the same vegetated wall requirement, increasing the potential for new ideas centered on a theme. Changes will be made but the second studio will use the same written style analysis from journals and books to show difference while still preparing the students for thesis year.

Starting out: Questions in a New Framework Studio (Full Studio)

Basis for the Development of the Analog Design Method

These are some of the concerns or questions that students could have while developing analog, or hand rendered designs: what type of media, what type of paper, what type of modeling style? Knowing what to use and how these materials and tools interact with each other can make a great deal of influence on the representation of designs. This is not mean to make the decision for them, but start their exploration into methods of representation.

The first question is: what kind of media? Different types of media can have different effect and qualities depending on their use. This was the reason for understanding color theory and implementing it through watercolor in the case study in the literature review. Types of media that have been used before are better to review as experience is the best teacher. This list is a beginning to the possibilities and choices students have at their disposal and is based on the researcher's educational experiences. The list includes: pencils, pens, Prisma markers, watercolors, pastels, charcoal, acrylics, xylol printing and transfer, and mixed media techniques. The second question is: what type of surface or paper? The tooth, the weight or thickness, and the acidity of the paper or surface can impact the representation of the design. Finally, there are the modeling methods and materials of hand modeling, the wood shop and metal shop. This modeling can be done at full scale and at other scales.

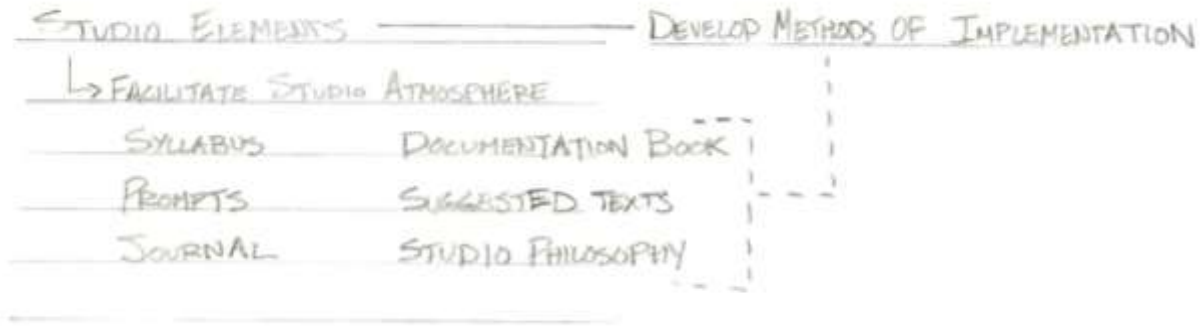

Figure 52: Studio elements for implementation

Basis for the Development of the Digital Prototype Tool and Design Method

The other method of designing can be done with the assistance of computers. This is called computer aided design (CAD). As with hand drawing, there are concerns or questions that students could have while developing digital or computer rendered designs: what type of program, what type of operating system, what type of modeling style or capabilities? As with hand drawing, knowing the capabilities of the tools at hand can produce more accurate or desired representation. Know the ability of the student and the program will allow them to work more easily and allow for more exploration in design.

The first question is: what kind of program? Different types of programs work in different ways and may or may not be intended for the work being done or the style of representations desired. This creates a situation where the computer programs being used might be known programs rather than the program designed for the situation as learning new programs takes time. This was why more generalized 3 Dimensional designing programs were selected. This will allow students to use known programs as a base and then adapt these programs with desired plug-ins. Also, the programs selected are ones that the researcher and teacher has some familiarity with to teach or help others. As with hand drawing, the following list of digital programs is a beginning to the possibilities and choices students have at their disposal and is based on the researcher's educational experiences. The list includes: AutoCAD, Revit, Photoshop, Illustrator, among others. The second question is: what type of operating system is being used? The be it a PC or a MAC computer, the familiarity the designer has with the interface can impact

the representation of the design. There are the modeling methods and materials of computer modeling, which can be done at many scales such as Laser CAMM, CAD CAMM, and resin based 3d printing.

Finally, the student can also use any kind of mixed methods of hand and computer usage to create representations. Design by hand or by computer is not mutually exclusive, nor should it be. Students often mix methods in order to produce a finally representation in studio environments. They also learn many things from other students in a collaborative atmosphere. This should be encouraged so that the methods students use can combine that which they are familiar with and not familiar with to learn new skills or methods of design.

Developing Studio Methods and Implementation

The point of knowing these options is to have both the student and the teacher develop a more individual plan together. This is because every student is different and responds according to previous experiences and talents. Therefore the plan does not need to force a certain method, but provide a basis for the student to learn. However what is this method of encouraging the student to learn and explore design and representation? The use of a teaching philosophy is important to guide a professor through their own teaching. This philosophy is something that evolves over time and responds to new experiences. Next is to implement a studio where the students feel confident that they can explore without risk. Students are inherently worried about their performance, and we as teacher most show that learning is not always tied to assessment. Then a studio syllabus is necessary to explaining the expectation of a studio to the students beforehand. In the syllabus there can be the project prompt so that the studio can begin with a project in mind. During the studio period a journal is kept to chronicle decisions and express though on the project and studio. Finally, each student will produce a book on the work done during the studio as a final method of representation after final review presentations.

From this overview, a curriculum will be established for a studio application using vegetated facades. Before the end of the project a studio will experience a teaching method based on how color theory interacts with vegetated facades and how this can be applied to both hand and digital representation. The work created from the study period will be used as references for the development of further studios, teaching methods, and representational methods for the researcher or professor. The

work will also see if any students engage the vegetated walls in regards to color theory without direct instruction.

The Elements of a Studio

The elements of a studio are critical in determining the ability of students to not only learn material, but design to their full capability. The necessary components include a studio syllabus, prompt, journal, reviews, and final book. The amount of professor involvement without being overbearing is necessary to develop interactions between students and students and the professor, have helpful presentations and meaningful desk crits. All of these help to develop the student's ability to speak to and represent their design work. The concept of a studio is important to a greater understanding of design through exposure and experience. These studios should not be forced, that there is a time and place for all experiences. In the curriculum set forth by Virginia Tech, setting a vegetated assemblies studio would be best during either semester of fourth year for those students who do not participate in Europe travel. The second half would better serve the students as an introduction for thesis. This would turn fourth year into a new experience rather than being perceived as a requirement for thesis year.

Studio Syllabus

The first element is the studio syllabus. This document serves as an introduction for the students to the new studio environment. Typically the syllabus is a reference for the student, but is commonly filled with information should the need for it arise. This can include information of the instructor, studio philosophy, learning goals, suggested texts, course topics, work evaluation, conduct policies, the honor code, accommodations, among others. The syllabus can also set the tone for a studio, but is not a replacement for the professor's ability to interact with, and build experience with the students. The project prompt is where the work requirements are presented in a concise form. An example syllabus is included on the next few pages.

SA+D (School of Architecture + Design)
ARCH 5015/5016 – Graduate Studio
MWF 1:00-5:00pm
T/R 2:00-5:00pm Cowgill 000

Course Policy Statement & Syllabus

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A [Re]-Introduction to Studio

Philosophy of the Studio:

Architecture exists as an example of personal interactions with the surrounding environment. There are many different interpretations of this theme; however, the particular method I choose to subscribe to is the idea of man as a metric for the development of space and impression. This is not to say that all of architecture is dependent upon the individual. It is the interface that the individual has with the architecture combined with the interface that the architecture has with the surrounding environment which creates a dialogue that informs design.

I suggest that we can discover ourselves everywhere, in every place and time, by doing similar things in a different way, and behaving differently and reacting differently to the similar stimuli. That man will not be entirely subject to the constraints of the structure but will have the ability to interact with and understand the built environment.

We, as designers, people, and users all have a sense of place and connection to the environment in which we live. To design a building that is not in some way responsive to the surrounding conditions is simply a lost opportunity for a more compelling intervention in architecture. This sense of place within the realm of architecture is created by the deeply personal memories and experiences from each individual. The impression that one gets form the space and its contact with the surrounding environment, should be immediate, that architecture shows us its worth.

This idea of an innate connection to the environment, termed Biophilia by the biologist Edward O. Wilson, is not new. Man first existed in nature and then used architecture to provide shelter and a sense of place. This harmony with nature is not only being sensitive to the environment, but also sensitive to the cyclical methods that nature employs and how these cycles can be integrated into design of responsive architecture. It is important to understand that this style of architecture is not reactionary, but a combination of natural and man-made stimuli to create space as a *designed response*.

The past, present and future must be present in the mind of the designer as a continuum. This creates perspective and context against sentimental historicism, modernism and utopianism. This is not to say that the designer is solely focused in the past, but rather is aware of the past, the past that has become the present and is projected into the future. The way in which a designer operates then influences future interventions in architecture which may or may not be his own.

Therefore, the designed response is not an act that is applied to a particular project, but a habit that is maintained by the designer, ingrained into the design process. When a method, such as this sensitivity to the surrounding environment, is central to the design from the beginning, the response is stronger and

more developed. This is not to say that a project must be only one pure idea. Design should have many layers that build the intensity of the design, without adding unneeded complexity.

Using these concepts, my architecture comes from the personal understanding of the situation at hand in reference to the surrounding environments. Each individual then interprets that specific interaction of man in architecture in part by the accumulation of an infinite sum of human experience in the connection with nature.

Learning Goals:

- Participants will explore how to become critically engaged, internally and externally reflective designers in their own designed responses and how to maintain a studio culture.
- Participants will begin to understand studio as the facilitator for life-long learning in design.
- Participants will acquire the necessary skills to represent and discuss personal and colleague projects, moving toward and creating a personal practice of architecture.
- Participants will gain a general understanding of common code practices and environmental design.
- Participants will gain a knowledge base for web design for the dissemination of ideas and maintaining a portfolio of work electronically as a method to showcase their work as designers.

Suggested Texts:

- Architectural Graphic Standards
- Mechanical and Electrical Equipment for Buildings [MEEB]
- Nature's Open Secret: Introductions to Goethe's Scientific Writings
- *Other texts as the students deem integral to their design process*

Course topics:

Topics to be explored concurrently:

- Architectural/Design Positions
- Site Evaluation
- Environmental Design
- Environmental Building Systems
- Building Code Requirements
- Energy Code Requirements
- Representation and Presentation Skills
- Studio Culture
- Web Design and Presentation
- Professional Development
- Design Research
- Design Competition Participation

Required Work/Evaluation:

- All Evaluation is based on attendance in the form of: the completion of assigned studio projects in a professional manner and engaged participation in critiques and reviews.

Course Conduct/Policies: Virginia Tech Studio Culture Policy (Learner-Centered)

Introduction

In the School of Architecture + Design at Virginia Tech, priority is given to a unique environment that directly contributes to the student's architectural education and to the initiation of a life-long pursuit of learning. The goal of the School is to make an environment where students learn to take responsibility for their own education with the guidance of the faculty and within a holistic framework. The faculty is primarily responsible for establishing the necessary environment for the student's educational growth.

The faculty opens the intellectual horizons that challenge the student to continually expand and deepen their critical understanding of the discipline of architecture.

The Design Laboratory

Both the students and the faculty have a responsibility to contribute to making the laboratory an environment that is respectful of individuals, shares in the intellectual life of the school, and is conducive to disciplined work.

The laboratory is an environment in which the multiple facets of the student's formal education are brought into discourse with one another.

The School recognizes that it must allow adequate time for such an educational process to take place. The faculty carefully assess and structure the requirements of the work assigned to students so as to give the students adequate time for a committed investigation of the inherent complexities of each project.

At all stages of the design process architectural education requires the ability to think clearly and coherently, to form sound opinions and to make sensible judgments as part of an ongoing process. The form of this thought and the values established is made evident in writing, discussion, representation, and making.

The School expects its students to develop a sense of self-reliance and independence; to discipline themselves towards diligence in their working habits; to give full attention to the quality of their work; and to adapt to different lab environments. The School values creativity for what it can offer to the broader dialogue taking place in the lab. It expects its students to maintain an open attitude to constructive criticism and advice.

Students should recognize that the most valuable insights emerge from within their ongoing dialogue with the work, not from judgment on the finished project. The School emphasizes ongoing dialogue and discussion rather than final judgment. An important component of the laboratory will be regular group discussions of the students' ongoing design work and more public discussions in the form of exhibitions. Each discussion is primarily intended not as a critique of the student by the faculty, but as a mutual dialogue about architecture.

Students are encouraged to think of all the faculty of the School as "their" faculty, and not only their particular lab instructor. Interaction between students in separate labs and between students in separate years of the program is encouraged.

The weekly routine of design lab will be infused with lectures and presentations by an array of faculty and visitors. Students are expected to attend as many of these presentations as possible, and to participate in the discussions that they initiate.

All students are encouraged to establish a trajectory of investigation that will sustain a continuing creative life within the profession.

The School believes that the continuing health and development of the discipline of architecture demands students who are capable of critical thought about the principles and practice of their profession.

The School believes that every student's work has the capacity to influence future growth and innovation within the discipline.

The VT Honor Code -- Academic integrity is an important and valued part of all of the work we do. As in all graduate courses, the tenets of the Virginia Tech Graduate Honor Code apply and will be enforced in this course, and all assignments shall be shall subject to the stipulations of the

Graduate Honor Code. For more information on the Graduate Honor Code, please refer to the GHS Constitution, located online at http://fbox.vt.edu/studentinfo/gradhonor/ See also http://www.gradhonor.grads.vt.edu/ for more information.

Accommodations for Students with Dis/abilities -- Accommodations are available for any and all students with a dis/ability. We can work with you to arrange for suitable accommodations, so please don't hesitate to speak with me early in the semester. Students should also contact the Services for Students with Disabilities (SSD) with questions about specific information regarding available services: SSD, 310 Lavery Hall, 231-3788 or ssd@vt.edu.

Virginia Tech's Principles of Community -- We value and adhere to the VT Principles of Community. Please come to a personal understanding of and familiarize yourself with the VT Principles of Community described below:
Virginia Tech is a public land-grant university, committed to teaching and learning, research, and outreach to the Commonwealth of Virginia, the nation, and the world community. Learning from the experiences that shape Virginia Tech as an institution, we acknowledge those aspects of our legacy that reflected bias and exclusion. Therefore, we adopt and practice the following principles as fundamental to our on-going efforts to increase access and inclusion and to create a community that nurtures learning and growth for all of its members:

- We affirm the inherent dignity and value of every person and strive to maintain a climate for work and learning based on mutual respect and understanding.

- We affirm the right of each person to express thoughts and opinions freely. We encourage open expression within a climate of civility, sensitivity, and mutual respect.

- We affirm the value of human diversity because it enriches our lives and the University. We acknowledge and respect our differences while affirming our common humanity.

- We reject all forms of prejudice and discrimination, including those based on age, color, disability, gender, national origin, political affiliation, race, religion, sexual orientation, and veteran status. We take individual and collective responsibility for helping to eliminate bias and discrimination and for increasing our own

- We pledge our collective commitment to these principles in the spirit of the Virginia Tech motto of Ut Prosim (That I May Serve).

Studio Project Prompt: Vegetated Assemblies

ARCH 4016
Focus Studio: The Choreography of a Living Wall:
A Design Method that Integrates Color Theory As it Relates to Vegetated Assemblies

Spring 2015
Instructor: Kenneth Black
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This studio course seeks to explore the boundaries between nature and its application in architecture. This project will serve as an impetus for you thesis design project in the coming year. The exploration will be through the design of a site for a structure with a vegetated façade or wall. The program and programme of the project can be anything you want to explore.

In the project it would be ideal to be able to explain its sense of place, that after having a map of the place an appropriate intervention is developed, and that the site be a place you can visit and explore.

As a semester-long project each student will develop a site proposition and at least one proposed building in detail. The proposed designs will be summarized in a book that will be due the last day of class. You are encouraged to explore ideas about architecture that may be translatable toward your thesis year. Finally, each student will also maintain a work journal that describes their process and evaluation of the studio and professor.

Grading:
Site Proposition ……..… 30%
Design development ……..60%
Engagement/
Class participation……..… 10%
100%

Studio Journal

The journal facilitates the student's ability to be self-reflexive, and to be able to review their personal work and design method. The students will record thought or sketches over the course of the semester. These recording should pertain to the studio project or to similar concepts in design. The purpose is to have the students be able to articulate and write about their own and their studiomates' projects. They should also be able to chronicle the method and design process they implement to the project design. Finally, the journal will allow them to critique the teaching method used in the studio in detail and at leisure rather than only at the end. Again, this journal will be a part of the participation grade, but not reviewed for content until after grades are completed. This allow for candid and honest review of the teaching method and process without perceived repercussions.

Studio Final Book

The final studio book is a compilation of work from the semester. Each student is responsible for the format and content. This final book or box is separate from the journal. The difference between the book or box is that the book is a bound copy, while the box is set up more like a series of plates. These plates are the equivalent of stand-alone pages. The box also becomes an opportunity to design.

The book will allow the student to write about the project, show a series of work, to practice for the thesis book for documentation that will occur at the end of the B. ARCH curriculum. The book will cover the topics the students explore in relation to the site and vegetated wall. It will show the site proposition, design process, and final product of the design. The open format and page size allow the students to explore different methods without being confined to a particular set of requirements. The students will hand in both in hard copy and in electronic copy.

The work from these books will be used to see how student implement the design method suggested, while infusing their own personal architectural style. The images and work will be used in the research so I, as the researcher, will need to ask for permission for using their images and work later in the process. From the collection of these images and the self-reflection on their individual methods, a synthesis of the different methods will be devised to use as an introduction for subsequent studios.

Delphi and the Creation of the Digital Prototype Tool

This is the beginning of how the tool will be used in terms of a framework and its verification. The next concept is the use of a Delphi and the development of the prototype tool's interface map. The Delphi will be used at multiple stages to verify the direction of the tool. The first instance will be during its development as alpha testing. This series of tests will take 'experts' that can evaluate the usefulness and the interface of the tool to determine next steps of the direction of future development. The initial map of the prototype tool's interface is below:

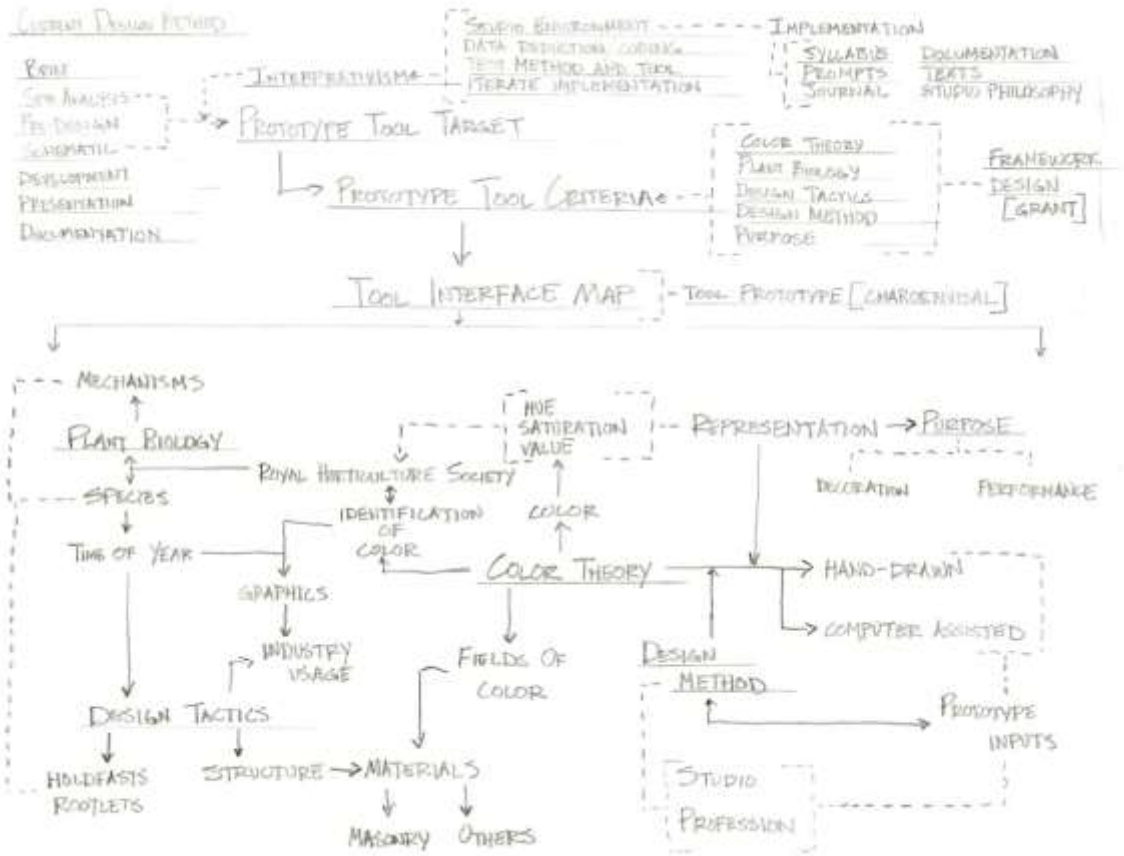

Figure 53: Initial Tool interface map for alpha testing

Using this map, a process and framework will be developed to allow users to engage the criteria explained in the framework section (color theory, plant biology, design tactics, design methods, and final purpose), in conjunction with interpretivism and the As-is design methods in a studio environment. A second testing of the process will be implemented in a studio environment to measure its effectiveness. A

final Delphi will be used among students and/or professionals to see if the prototype tool is more suited for academic or professional development.

A survey will be included in the use of the design tool based on the expertise of the individual. The survey will include questions similar to the following, based on the work of Dr. Grant and Dr. Thompson in a survey from a previous project.

Did you include vegetated assemblies in your studio project?

Were you interested in vegetated assemblies before the project?

Have you used vegetated assemblies in a project before?

What kind of drawing techniques did you use? (You can select both)

What kinds of techniques did you use during the project? For example what kinds of pens of pencils or paper for hand-drawing, or what programs for computers?

I understand the considerations involved in designing vegetated assemblies.

A design tool for vegetated assemblies would be helpful in your design process.

Architects provide valuable insight to vegetated assembly design.

I understand the benefits and qualities of installing vegetated assemblies.

I understand how I can design vegetated assemblies in studio.

Building users provide valuable insight into the design of vegetated assemblies.

I understand the risks and complication to design be including vegetated assemblies.

I have familiarized myself with other projects that have used vegetated assemblies for the project.

What were some of the projects?

I know the general types of vegetation that will thrive on a vegetated wall.

I know the general types of vegetation that will thrive on a vegetated roof.

I know the general types of vegetation that will thrive on a vegetated facade.

I understand the difference between the various types of vegetated assemblies.

I understand the major obstacles to implementing vegetated assemblies.

Vegetated assembly suppliers provide valuable insight into vegetated assembly design.

From this initial exploration to how the process is currently performed in the studio, the tool can begin to reflect the nature of the design process. This tool will then be introduced back into a studio environment to see how the design process is influenced and assisted by the addition of the tool.

From this introduction of the tool into the design process another set of questions will be introduced on top of the ones described, mainly focusing on the efficacy of the tool and its usefulness. The tool at this time will be still refined before the use in the Delphi testing phase. The questions for the students in a future studio are below:

Did you find the prototype tool for vegetated facades helpful?

Is this a tool that might be fit for use in academia?

Is this a tool that might be fit for use in the architectural profession?

Does the tool meet your needs as a designer?

Does the tool appear to be over-reaching or overbearing on your design process?

Does the tool help to make informed decisions about vegetated assemblies?

Does the prototype tool have an acceptable body of knowledge for plants used in the industry?

Does the tool help to determine what kind of structure will be used for the design?

Does the prototype tool have an acceptable body of knowledge for color theory?

How was the tool used? Was it to refine ideas or solely represent possible ideas?

Was the user interface with the tool acceptable and how could it be improved?

When was the tool used in the design process?

Who do you believe this tool would be most useful for?

In your opinion, how can the tool be used?

What kinds of disciplines or professions might find the prototype tool helpful?

Would you use the tool again in your design process?

These questions will help to determine if the prototype tool is balanced and does not favor a particular type of style of design. One of the main driving factors is to confirm that the prototype tool does not favor a particular system or method of design, and is a scaffold for design support. After this phase of reviewing the prototype tool in a studio on theoretical projects, the tool will be used on the Electric Car Charging

station in order to find any more inefficiency. This process will test how the representation of the project in the tool relates to the actual constructed building in an attempt to calibrate colors or other topics in plant biology, color theory, design tactics, design method, and purpose.

The immersive case study will also use the photographic and observational analysis to see how the vegetation develops over time and how this can be integrated into the process or a tool. This observation sheet is shown in table 4, and pictures will be taken at each instance of observation in the morning, afternoon and evening. After reviewing the tool in the immersive case study, the tool will be revised again and then used in the Delphi stage. This will involve using professionals in the form of students who have architectural design experience and from professionals in design education or in professional firms. These three groups will cover the students at the beginning of their prospective design careers, those who teach them professionally, and professionals who could use the tool in their design processes. The same questions will be used as in the first studio and in the revision studio design, as well as any questions developed from the use of the tool in the immersive case study.

From this Delphi, the tool will be revised and the used again in another studio for a final implementation before considering for use in studio as a design support structure without the researcher's presence or supervision. At this time the tool would still be in its infancy, and would be continuously developed over time.

Significance of the Methodology in Developing the Prototype Tool

While the process and methodology is simple, the significance and implications of teaching future professionals is astounding. One of the most important qualities that a designer must have is the ability to be self-directed and interested in the profession. This is sometimes assumed, rather than confirmed or instilled in students. We, as educators assume that students are interested because they chose to be in college. Every student is different and the means and reasons for being in the studio are different. Therefore the method and prototype tool are there as a means to an end for showing students their own potential. From this method, there should be the development of not only a prototype tool for designing vegetated assemblies for each student, but also a design philosophy in architecture.

Phenomenology looks at how we interact with the world and how these experiences form our perception of the world. These topics of vegetated assemblies, color theory, plant biology and their synthesis give researchers a basis for when asking, interacting with a situation. It develops what is our filter, our lens, which informs our course of action. Every student has a different set of experiences that leads them to be the person that they have become, are, and will become. In design there is a combination of not only what we want to become (desires, goals), what others see us becoming (reputation), and what we came from (experiences). These three things show us how people make the decisions that inform their own architecture and how it is perceived and developed.

Educators and students are not statistics in a system, but that if we put in the time and effort, there is the opportunity to become an expert in or own spheres of influence. There is a struggle, but it is the goal of what educators and students wish to become that drives most to continue. By pursuing goals, we slowly alter our impressions of that which is within. And as we change our own inward image, we see the outward image we project to others will change as well. So, when we consider the history of the university, the history of the profession, and our own history, we can see where we can fit in, and how our experiences have changed us. For example, at the beginning of my undergraduate studies I had never drawn before – I chose architecture – and after five years, I can no longer imagine explaining something without somehow using images somewhere in the discussion. As a student, researcher, and educator, I have started to hear the stories of others and have the opportunity to see an entire lifetime of choices, actions, and learning infused into a person. These are lessons that can not only inform our own path, but can be transferred to others as we continue to teach, or practice our profession in the future.

Therefore the method of teaching and developing the prototype tool through a studio will allow students to have an opportunity to create the method in conjunction with the researcher. This uses the process of teaching to define the method and implementation rather than impose a method on the students. By teaching a studio more than once, multiple iterations of the studio will refine the method and products. The more studios taught means that inexperience on the part of the researcher/educator will become less of a factor.

The most critical part of the method is that the students are equals in the research process and are an integral part, not just the experimented subjects. The method allows for choice in the development

of vegetated walls and the creation of an individual context for each project. The method creates a cohesive teaching method, but allows for a variety of final projects and design methods. The method is not looking for a uniform product, but a relatively similar method amongst the students by allowing for hand drafted and computer based designs.

4

Appendices

Building Biospheres: The Anatomy of an Artificial Ecology

Biosphere 2: Oracle, Arizona

By Kenneth Black

What would happen if cities needed to re-create themselves and their natural environments in completely self-contained structures? It would take re-enlivenment to the extreme, creating a series of new environments, forming an enclosed biotic system. Biosphere 2 enclosed 3.14 acres of the Sonoran Desert was completed in 1991 at a cost of $200 million (Allen & Blake, 1991) in an attempt to jumpstart a form of enlivenment and determine its survival prospects, in a completely artificial ecology.

Figure A: Biosphere 2: the glass enclosure at early morning

The Biosphere 2 Project

Biosphere 2 was a research project from the start. How would complete structural enclosure affect atmospheric cycles, ecological development, wildlife, and human physiology and psychology? The purpose of the project was to model a method for managing analog or mimicked human ecosystems at a large scale. This technology could then be used in planetary colonization as well as human refugia from possible nuclear winter or degradation of the earth. Biosphere 2 was also to serve as an architectural example for possible replication in cities (Snyder & Institute of Ecotechnics., 1985).

The project is all grounded in the work of Vladimir Vernadsky. (Allen & Blake, 1991; Gentry & Liptak, 1991), Vernadsky defined a biosphere as the nature that surrounds us and the environment we interact with. He split the world and people into three spheres: the biosphere, technosphere and the noosphere. The technosphere was created with the evolution of technology by humanity. The noosphere is the region of reasoning, remembering and decision-making (Allen & Blake, 1991; Vernadsky, 1986). Theoretically, over time, biospheres and their inhabitants become more complex, consuming and recycling more matter and energy that establish and maintain a more stable biosphere. The innovative part of the biosphere theory was that life was its own progenitor, that life creates the conditions for

maintaing and replicating more life. The site near Tuscon in Oracle, Arizona was chosen for its ecological diversity as well as abundant local expertise in ecological, technical, and agricultural personnel (Allen & Blake, 1991).

Mimicking all of the Earth in a Single Container

Biosphere 2 includes two anthropogenic biomes: agriculture and city, as well as five natural biomes: ocean, marsh, rainforest, savannah, desert (Allen & Blake, 1991; Kelly, 1990). The rainforest is one of the most interesting biomes, filtering light into a very dense, humid area. It is hard to believe that when this biome was planted, none of the trees were taller than eight feet. Now it is difficult to see the light from the exterior (Figure B). Everything that entered biosphere 2 would need to be useful in keeping the natural and man-made systems active. These biomes of the biosphere were re-created using actual flora and fauna species from each biome infused with a constructed façade. Not all parts of the biomes are completely natural. For example, tide machines to raise and lower the water levels, algae scrubbers to lower nutrient levels based on needs using a plastic tube with algae mat and a tipping bucket to aerate the water. In the savannah, a 'synthetic ecology' was implemented that allowed for more effective control of undesirable processes (Allen & Blake, 1991; Kelly, 1990). The savannah section of the project is so adapted to its particular biome that artificial disturbances were considered to mimic the difficult conditions for survival in the wild. Biosphere 2 adapted and mimicked all of its constituent biomes to suit the needs of its human occupants.

Figure B: light piercing through the rainforest

The boundaries between zones were crucial. Tall bamboo plantings shield the rainforest from the ocean; the savannah is between the rainforest and desert, and differences in water levels prevented undesirable saltwater backflow. Hundreds of different plant and animal species were infused into the mimicked biomes. Biosphere 2 even replicated natural extinctions by overloading the project with species and letting some die out (Allen & Blake, 1991; Kelly, 1990).

Manifestation of Technology to Mimic the Earth

Technology manifested in a variety of ways. A fan blower would mimic the winds, stream pumps would ensure the flow of water, the wave machine would mimic tides (Allen & Blake, 1991). The fan blower was necessary to force trees to grow roots laterally or they would grow and then fall over, unable to brace themselves properly. The one million-gallon ocean combined with the wave machine creates a half meter tide on a lunar cycle (Kelly, 1990). The architects were in control of the topography that would allow for specific niches for the biodiversity that would be introduced. It was thought that the replicated

Figure C: the artificial ocean

ecologies of the entire container would continue to re-enliven themselves automatically, evolving, renewing and growing.

The Biosphere 2 had to be completely sealed and a custom stainless steel liner that prevents the loss of air though the ground. A pair of 'lungs' or variable expansion chambers were constructed to compensate for the changes in pressure in the building during the day. As the sun heats up air on the inside of the space, the air travels via underground tunnels to the hemispheric domes to a rubber membrane with a metal top that moves freely in response to the changing pressure. To regulate the heat in the space, massive cooling towers, essentially massive waterfalls, cool Biosphere 2 without breaking the enclosure.

Due to the desire for Biosphere 2 to have a space application, it was necessary to seal all of the glass in the space frame. The degree of sealing that was desired was very difficult to achieve. The goal was to have only a 1 percent leakage, that every generation would experience a complete air turnover. Some sources claim an actual air leakage of was 3 percent, replacing the atmosphere every 30 years (Allen & Blake, 1991). Other reviews claim 5-10 percent leakage. Atmosphere within the space is surprisingly clean from the use microbes and fewer off-gasses from material choices and organic matter decomposition (Kelly, 1992).

After creating a separate atmosphere for Biosphere 2, the water system was installed to mimic the natural water cycle. This was attempted through the use of misting machines to produce artificial clouds within the container by pumping water up from below (Allen & Blake, 1991; Kelly, 1990). Then depending on the biome, water was diverted and kept mainly in the rainforest and ocean, not the savannah or desert (Allen & Blake, 1991). Drinking water was obtained from the condensation on the cooling coil in the moist air (Kelly, 1990). The pumps would have to work continuously for the system to function as design and a massive reservoir had to compensate for the uptake of water in the plants over time. Furthermore, human wastewater was filtered by mimicking swamps and marshes using slow moving water in vegetation and microbe-rich environments (Allen & Blake, 1991).

In Biosphere 2, technology backed-up natural systems, to solve needs and close gaps created in mimicking the environment. It was monitored by a technosphere (a complex computer-based monitoring and control system) to regulate and back-up systems from the biosphere. This nerve system controlled temperature and gas balances, controlled water including the rain requirements, rivers, humidity levels, storage, tidal flows, to nutrient scrubbers, and others. There was a sealing team called the biosphere emergency response team in case of leaks in the space frame. All of these systems had redundancies to reduce effects from mechanical failures (Allen & Blake, 1991).

Biosphere 2 succeeded in mimicking the biomes and natural cycles that were created, but what about the humans? Now the space needed to adapt these environments and cycles to maximize yields

for sustaining 8 people within the structure, as well as keeping the natural and man-made cycles going within Biosphere 2. This was accomplished through intensive farming. The soil in the farm section was the main issue to solve and as was composting soil to recycle nutrients without fertilizers. If fertilizers were used they would very quickly be in all the other systems which would be detrimental to the other artificial biomes. In this fashion the farm section as able to produce oats, wheat, rice, sweet potatoes, squashes, peanuts, beans, peas, and more. With fodder crops, domestic animals and a system from china involving tilapia fish, rice and azolla allowed for production of meat as well as vegetables (Allen & Blake, 1991; Kelly, 1990).

Re-visiting Biosphere 2: Re-enlivenment?

The cool fan-driven breezes off of the artificial ocean, the brine smell that was throughout the technosphere, the humidity of the rainforest, the pressure differential in the two lungs, are all experiences that can only be garnered in place. During a tour through project in 2014, it was explained that after Columbia University could not afford to keep Biosphere 2 operating, it shut the building down for multiple years. Without any climate control and human intervention the biomes continued to evolve and the structure remained intact. Perhaps the most energy intensive biome is the artificial ocean. During the period in which Biosphere 2 was shut down, the water turned black and putrid, however some of the original fish continued to survive and hermit crabs have been re-introduced since the ocean was restored.

Originally, Biosphere 2 was envisaged as a dynamic assembly of distinct biomes – replicated natures to ascertain an understanding of the effects of containment and the capacity for human survival control in a contained environment. No one now lives in Biosphere 2. The structure is a museum for tourists. The notion of an artificial human world is a deceased relic, under restoration itself as an historic artifact. However, it is also possible to interpret the entire project as an experiment in the production of hybrid non-human artificial ecologies, perhaps becoming a single self-contained living organism – a different manifestation of re-enlivenment. While Biosphere 2 did not fulfill its original mission and would not be practical for large-scale implementation on earth many lessons were learned about the design and construction of artificial ecosystems from this living laboratory. These are the greatest contributions of Biosphere 2.

Biomimicry: A Story of a Different Living Wall

Using Biomimicry to Re-enliven a Wall Design

There are endless examples of how nature has adapted to fit its local environment. Many of the examples can be found separately, but now these examples could be combined to make very interesting living walls. These include the interconnectivity of ecosystems, the energy generation from green plants in photosynthesis and sugar production, the generation of regular shapes with fractals, the process of heliotropism where plants that track the sun, the process of light production in bacteria, fireflies, and algae, the temperature regulation of dolphins, the self-cleaning lotus leaves, the lightweight and strength resistance in bee honeycombs and carbon fiber from trees, and the conical venus flower basket, and the production of color effects in Morpho butterflies.

All of these types of biomimicry can be used in a living wall system. However, where are these methods being used now? Photovoltaic panels with dye sensitized solar cells use the substrate of titanium oxide release to release electrons when hit with light. The bio-battery was developed by the French National Center for Scientific Research. This battery can be placed into plants and receives a charge from the process of photosynthesis; as sunlight becomes stronger, the amount of energy available increases within the battery. Fractals have been used in computing, graphic arts, literature, cinema, and music. These patterns help designers understand the more complex ways that nature operates, in terms of a visual representation of generative graphics. Fractals are also found in nature: in the structure of plants, bacteria, coasts, rocks, human physiology, ice flows, clouds and more. The heliotropism found in sunflowers can also be used in photovoltaic panels. A group of researchers at MIT are using two different metals that expand at different rates. Depending on the presence of sun the panels respond accordingly to track its path. Safety equipment and walls could be made of materials that respond to light conditions or have chemicals that mimic bioluminescence. Phase-change materials (PCMs) operate in a similar way to the fatty acids in a dolphin. The acid change phase and absorb heat or release it at certain temperatures. This change in phase helps to mitigate temperature differences. PCMs can be paints, panels, or pockets of material. Finally, the hydrophobic nature of the lotus leaves is mimicked in paints, and reduces the amount of surface area in contact to a minimum with water and dirt, staying remarkably clean (Ternaux et al., 2012).

The work of Pier Luigi Nervi in large span structures shows us the power of combining material explorations with structures to achieve greater expression and efficiency. Nervi used ‘ferrocemento’ which he invented (Eduardo F. Catalano, 2014; Pawlyn, 2011). ‘Ferro-cemento’ is “a thin, flexible, elastic and very strong material composed of several layers of fine mesh sprayed with cement mortar” which allowed for extremely thin shells to cover great distances (Pawlyn, 2011). This process eliminated formwork, which is the most time-intensive part of using concrete, thus it saved time, material, and money.

Nature uses ribs, shells, domes and arches to create structures, such as the amazon water lily and its ribs. These ribs follow the stresses and reinforce the top surface of the lily plant (Pawlyn, 2011). Nervi uses this efficiency in the Gatti wool factory with ribs and beams following the lines of principle

stresses (Cortes, 2014; Pawlyn, 2011). This project, as in nature, expresses the forces present in the specific structure rather than a generic solution to a structural problem. From the online version of the *Encyclopædia Britannica*, "[Nervi's] …highly rational and innovative structures resulted from a continuous process of devoted search and development, with an emphasis on modular construction, prefabrication, and extreme physical and visual lightness." (Eduardo F. Catalano, 2014). This shows designers that the potential for discovery and learning lies in the boundaries and intersections between individual subjects. The interaction of material innovation and structure led to Nervi's success, while biomimicry was not a leading factor. With all of these things in mind, what kind of vegetated and living wall could be made at the intersection between color theory in visual representation techniques and vegetated assemblies with biomimicry? As with the work by Nervi, the question presented is a combined issue of structure and materials to make a wall suitable for a living wall.

The beginning of the wall should start with the structural components. The living wall would need a modular wall panel system that could be replaced as necessary. In this manner the wall is not one unit and does not need to be full deconstructed to make repairs. This modular system can be pre-fabricated elsewhere and then brought to the site, saving time and money while increasing accuracy of the built product. The wall panels would be made of a 3D-printed honeycomb structure made of built up layers of carbon fibers. This method would allow for a very stiff, but light frame that the plants could be inserted into or grow on top of, depending on the scale of the honeycomb openings. Since the manufacturing utilizes the design strength of computers to change the scale of the honeycomb structure instantly. Now, with the advent of 3D printing, such structures could be rotated about an axis and mimicking the nature of the Venus flower basket to increase strength and make the wall a non-linear form. In the living wall, some of the honeycombs would have plants within the wall. These hexagonal modules would be made in a living fence style with medium between some type of screen. These screens would be made of Dichroic glass. This type of glass changes colors under certain lighting conditions and angles of view similarly to the Morpho Butterfly. During the winter, deciduous types of plants loose leaves, so a layer of color, reminiscent of the Morpho butterfly, will add color back into the façade during the winter. The dynamic color of façade reflects the nature of the ever-changing living wall.

The following other concepts could be within the same wall or used as a series of screens over the honeycomb frame. These other screens would work together with the living wall. Also, each hexagonal piece of the living could be interchangeable, only being used as needed. Depending on the orientation of the wall, some would have photovoltaics that mimic the method of photosynthesis, or even use the bio-battery which uses glucose and dioxgyen to make electricity like a plant. These hexagonal modules could rotate and follow the sun's path, increasing the effectiveness of the photovoltaics and the plants. Some of these panels could have the same enzymes that are present ion algae, bacteria and fireflies to then give off a bioluminescent glow and be a source of light during the night. Furthermore, if the self-cleaning methods of lotus leaves are used, perhaps undesirable growth can be averted on the wall. Other screens could function as night-time insulation using either conventional insulation or PCMs

(phase-change materials) can be used to insulate at night akin to a dolphin regulating its own temperature.

All of these walls could then be linked by computers to show temperature, light usage and other information and allow them to work in harmony for better results. Imagine all of these walls moving in unison to the environmental conditions, responsive to the specific moment in time. But no two of the walls are the same, manufactured to the individual conditions at each location. It is a story of how the group can benefit, while retaining the strength and individuality of each wall. This is to show the modular interpretation of an ecosystem, using layers and levels of interaction to create a cohesive whole.

The Wicked Opportunity provided by Living Walls and Re-enlivenment

Now the 'wicked problems' question is how this wall will be represented in design, what methods will designers use to conceive these new vegetated and living walls? Think of a wall that is truly living! Alive and responsive to its surroundings and these walls can produce color and be represented to the public for the synthesis of a unique design style. If the design of the wall is to be successful I believe it has to be considered as a part of the building and built environment, not only the wall itself. This is what this living wall will consider – the color theory of vegetated walls and adapted living walls which use biomimicry to serve as a facilitator for reconciliation ecology and therefore re-enlivenment.

Instead of having humanity working in the dark to restore an idyllic utopian past, living walls can coexist with the current built environment, reconciling the present conditions, while providing an opportunity for nature in the future. It is important to consider that re-enlivenment is not a single reference point, but a continuum, and shows a pattern of reconciliation for the built environment and nature. But what is the baseline, our target for the living wall when integrating it with the built environment? The target should not be looking for a final restored state, but a balance between humanity and nature. The goal should be to bring nature back to the built environment, creating a sense of stewardship, a sense of ownership as co-existors in re-enlivenment. When a place is re-enlivened it not only benefits ecology, but also humanity, for we are a part of the earth's ecology.

Reconciliation ecology is part how humanity can protect and utilize ecosytems for mutual benefit. It is not the answer to reservation and conservation ecology, but another aspect in a family of ecological styles. (Rosenzweig, 2003). The built environment is where we as humanity live, work, and play. Therefore, much of Rosenzwieg examples are of humanity carefully moving into natural environments, as well as natural environments slowly moving into our built environment. The habitats that will be created by reconciliation ecology, such as a biosphere like Biosphere 2, must respond to the species that will live in them, or be varied enough to take a multitude of potential species. The most important aspect of reconciliation ecology is active management and careful observation of habitats even within the built environment.

The vegetated wall or vegetated façade [living wall] shows potential in being one of these concepts that supports both enterprise and the ecology of a place. Enterprise has built an industry about crafting and maintaining vegetated walls and facades, and with all of the plant life, different forms of

ecosystems can be brought to otherwise barren spaces in the built environment. The synthesis of tasks, of information, of stimuli is how the natural world works to respond to the changes in the environment. These adaptations for survival in nature are what humanity needs to focus on to become competitive in an era that will become increasingly about reconciliation ecology and re-enlivenment. These systems do not have to be complicated. This explanation of a living wall is not the answer, but a beginning for continued explorations into what a living wall, can and could be in the future. Living walls can serve as a facet of re-enlivenment for both humans and wildlife in conjunction with each other, facilitating reconciliation ecology. Re-enlivenment can combine the potential that resides on reservation, conservation, and reconciliation ecology mindsets. Since re-enlivenment does not need to be pure, the same way the Biopshere 2 was not pure, it can be authentic in human nature, that the effort and intent are present, with a variety of results. Re-enlivenment is not a binary argument to be won or lost, but a continuum that yields humanity's interface with nature and the built environment. Thus a continuum shows possibilities rather than limits for humanity and nature.

The next step is to use the knowledge combined from previous work, in terms of color theory, vegetated and living walls, biomimicry and the specific Appalachian mountain climate and apply that to the method and process of designing such walls. Through the process of iteration and ideation computers and the knowledge of different disciplines becomes necessary to a more complete understanding of the wall, its potential and the vegetation used. If the study is going to be able to show ideas like this new living wall, what kind of programs will be used?

Wicked Problems in Studio

Interdisciplinary Design

In many of the mission statements, colleges and universities have stated the desire to give students an interdisciplinary education. These types of programs are interesting as they have the potential to bring seemingly unrelated things together, producing a wide variety of high quality work. These degrees and programs manifest themselves distinctly in different colleges and universities. No single method of implementing an interdisciplinary degree or program is universal, as interdisciplinary education reflects the opportunities and skills present in the students and faculty. The question being: how do universities actually do what we, as students and faculty, are told is desirable?

The main focus of the work is to see how the interdisciplinary degrees and programs differ over a wide variety of institutions. Simply, the difference found between an interdisciplinary degree and a program is that a degree is credit based and is a conferred degree upon graduation. An interdisciplinary program is a program that combines different styles of thought and study together to create an atypical learning environment. This can either be through an individual person's education, or as a group of students working together on a project.

After reviewing a wide variety of degrees and programs, the principles derived from the reviewed programs could then be used in a class or program in general design. This experience is based on different scales of learning, utilizing the potential of immersive case studies to teach knowledge. Furthermore, interdisciplinary research is an alternative to disciplinary work, as a part of a rising movement in the university environment. However this process of thinking is not novel as research suggests that interdisciplinary thinking has its beginning in Greek philosophy (Klein, 1990).

Interdisciplinary programs have made headway in the last couple of decades and continue to be more common in higher education. Over time these programs can become communities of learning and engagement that serve as alternatives to traditional disciplinary, or ‘silo” communities. This discussion of the literature will not decide or prove the efficacy of such programs, or determine interdisciplinary programs as a superior method. This study is done to reflect a gathering of knowledge of how such programs manifest in higher education and to show an example of what can be done in this method of teaching and learning in a specific case relate to the author.

If we consider interdisciplinary and attempt to define such a broad concept, we find that there are different groups or methods of creating such degrees or programs. According to Chandramohan and Fallows, there are three groups: joint honors degree or major/minor combinations in which the two subjects are considered quite separate from each other; multidisciplinary examples that draw separately from separately from several disciplines to build up degrees with a number of components that retain their distinct disciplinary perspectives; full interdisciplinary programs in which elements from different disciplines are woven closely together to derive a wholly integrated approach to study (2009).

These new areas of study as described by Chandramohan fall outside the present labels that have been given to disciplines. The concept of Interdisciplinary also then suggests disciplinary and the

delineation of different area or territories (Messer-Davidow, Shumway, & Sylvan, 1993). There are three main reasons for the creation and continued use of disciplines to define education: cultural, organizational, and scientific.

Some of the conversation about 'interdisciplinary' has been complied by Martin Davies, Marcia Devlin, and Malcolm Tight in *Interdisciplinary Higher Education (Davies, Devlin, & Tight, 2010).* People need to categorize and define one's surroundings, to take advantage of different areas of study and define them, and be rewarded economically through a structure system of classifications (Boisot, 1972; Chettiparamb, 2007; Lattuca, 2001). Disciplines also cause faculty to have loyalty to tier own discipline that can overpower interdisciplinary approaches (Becher, 1987; Clark, 1987; Donald, 2002; Frost, 2003). These traditional or disciplinary labels can be suitable for teaching, but not accurate for use as research or faculty labels (Pinch, 1990). These interdisciplinary groups exist largely due to problem and mission – based problem and goals. Researchers work on problems not in disciplines. Examples of mission or research include the Human Genome Project, biotechnology, molecular biology, risk assessment and technology assessment (Gibbons, 1994).

These research projects and new developments in academe have and continue to blur the disciplines, relocating scientific, technological, and artistic work from particular questions of disciplines, towards missions and research. This accelerated of multi-faceted thinking in research is a result of four factors: the inherent complexity of nature and society, the desire to explore problems and questions that are not confined to a single discipline, the need to solve societal problems, and the power of new technologies." ((COSEPUP), 2005). This layering of complexity is formed from a variety of sources, mainly that the "process of learning and research is additive" (Klein, 1990) and that an interdisciplinary approach is "synthetic with a central focus" (Kline, 1995). This allows researchers, faculty and students to build on previous experiences to further academic or professional goals.

These two different methods of engaging work in academe should not be contradictory or at odds with each other. Rather, interdisciplinarity and disciplinarity or specializations are mutually reinforcing strategies and could be used together to achieve results. Klein states that this relationship between is not a paradox but a productive result of two methods joining together (Kline, 1995). The method of hybridization in interdisciplinary projects that this suggests is in both form and process (Dogan & Pahre, 1990). Furthermore, disciplines and specialties interact, and produce results, but not necessarily new forms of disciplines (Dogan & Pahre, 1990). This is to say that while faculty and students may come together to solve a particular problem, each brings the knowledge of their discipline, rather than attempting to create a new one during the task at hand.

What does this mean for the students in higher education? The theory of interdisciplinary thinking and interactions is commendable, but the translation to practical implementation in education is critical. Moreover, it is interesting that the concept of interdisciplinarity is not limited to the United States. It is important to look at the concept of interdisciplinarity at a number of different scales, and theories. There are some requirements or conditions that make an interdisciplinary approach useful, not forced upon a situation.

There are different methods of implementing interdisciplinarity in programs, projects, or at institutions. When trying to use or include interdisciplinary approaches in educations, there must be necessity to have interdisciplinarity in a given situation, to have reason to introduce and pursue it. The group that the interdisciplinary approach effects must collaborate in the approach, having a system to support such endeavors; that when implemented there is a balance between disciplinarity and interdisciplinarity. Moreover, it is important to keep a historical perspective on interdisciplinarity and its role in the specific institution. These approaches require strong leadership in delivering interdisciplinary programs and are commonly linked with academic development. Finally, more engaging teaching styles can reinforce these concepts for students (Davies et al., 2010).

Within the larger realm of interdisciplinary teaching, there are varied types and meanings of interdisciplinarity. Multidisciplinary is when there are discrete and autonomous disciplines. For example the study several or multiple disciplines that contribute on a single research project, but each stands alone. The individuals involved understand the co-existence of multiple disciplines without knowing each other's individual discipline (Petrie, 1976). Cross-disciplinary uses techniques from another discipline to study a current phenomenon without learning anything from the borrowed discipline (Davies et al., 2010). Pluridisciplinary is where two disciplines combine expertise to address a common concern when the topic is too complex for one discipline (Heckhausen, 1972; Max-Neef, 2005). A transdisciplinary situation occurs when two disciplines are no longer distinguishable and merge to form a new discipline (M. Davidson, 2004; Max-Neef, 2005; Rowland, 2006). As evidenced by the emergence of fields like biochemistry and materials science, those pioneering collaborations may evolve into a field of their own (Becher & Trowler, 2001).

There are both intrinsic and extrinsic drivers to interdisciplinary research. (Klein & Rhoten, 2004). Science perpetuates itself with new discoveries; therefore its own intrinsic factors derive from scientific advances. The scientific disciplines further specialize knowledge, creating the need for interdisciplinary teams to solve issues and conduct research. The extrinsic factors to interdisciplinary work are created from societal problems or interests and associated funding. This creates and interesting dialogue between those who research and those who fund it. The National Science Foundation (NSF) has funded interdisciplinary research and education (Hackett, 2000). The National Institutes of Health (NIH), specifically in the biomedical sciences, funds research as a key to knowledge advancement ((NIH), 2003).

Every situation in education is different and demands individual attention upon implementation. Furthermore, universities need to consider when such approaches are relevant or useful and if they can bring advantages to student learning not in typical disciplines. At the same time these different methods should not hinder the current disciplines which commonly provide a base knowledge set for students in academe. From this base knowledge students are then able to move into the types of interdisciplinarity such as multidisciplinary, cross-disciplinary, pluridisciplinary, and transdisciplinary. Regardless of the name given to an academic situation, students should be encouraged to learn in a manner that will sustain them in the profession, to maintain critical thought and to influence future growth.

As there are different types of interdisciplinarity, there are also different methods of implementation based on location, either abroad or in the United States. These differences can stem from issues such as cultural differences, policy differences, and program implementations. Then at a given institution there may be differences in not only the language of the term interdisciplinary, but also the programs that develop based on the disciplines and faculty involved. Finally, the knowledge around interdisciplinary programs can give rise to new student-led programs and initiatives with faculty support.

The first example is the REU in Interdisciplinary materials and Physics through PSU (Pennsylvania State University). An REU is an acronym for Research Experience for Undergraduates. In this particular program, students are partnered with a variety of mentors from different disciplines. While the program is labeled as an interdisciplinary program, it also falls under the multidisciplinary typology, as students are working with one field of study, but are exposed to others. The REU is possible through a Center for Nanoscale science that is associated with the school (PSU, 2014). The National Science Foundation (NSF) is responsible for funding many of these opportunities through its REU sites programs. These programs are possible from the directed funding that the government provides to educate the next generation of scientists and engineers.

While the REU sites program is across many different institutions, funded under the NSF, there are opportunities generated by specific institutions for groups of disciplines. In the design fields an interdisciplinary approach to the built environment is becoming the trend to successful practices and learning techniques. These disciplines demand insight and sensitivity to cultural, environmental, social, structural issues of a place. At the University of New Mexico (UNM) there are graduate certificate programs that have been created to merge disciplines together. Historic Preservation and Regionalism combines preservation techniques with contemporary planning and design to engage with history culture and place. The Urban and Regional Design Certificate seeks to improve quality of life through research and physical design of cities, suburbs, and towns. UNM also performs outreach in the form of applied projects such as the downtown Route 66 revitalization. UNM is also testing a cross-disciplinary program in Design and Public Health (UNM, 2014). The Graduate School of Design also has worked with interdisciplinary concepts (GSD, 2012).

The University of Texas School of Architecture (UTSOA) has built two degree program that allows graduate students to build their own studies. These programs were added to the existing infrastructure that UTSOA. The two programs are the Master of Science in Architectural Studies (M.S.A.S. [Interdisciplinary]), and the post-professional Master of Architecture, or “M.Arch II”, (Interdisciplinary Studies). These degree programs allow students to use the resources present at the university from a multitude of disciples to define their own study (UTSOA, 2014). One example at Virginia Tech is the ICAT program. The Institute for Creativity, Arts, and Technology (ICAT), works as a catalyst for trans-disciplinary research and art, educational innovation, and scientific and commercial discovery. The program attempts to find a new method of thinking and research through the melding of disciplines working as a “trans-disciplinary living lab” (ICAT, 2014).

What can be distilled from all of the different examples and then added to a design studio? While every discipline is different and based in its own knowledge base, the need to work together with other professionals requires teamwork and the ability to seek out expertise as necessary. This expertise is commonly found in the divisions that disciplinarity creates and maintains. Of the different types of interdisciplinarity: multidisciplinary, cross-disciplinary, pluridisciplinary, and transdisciplinary, one fits easily into the mindset of design. Multidisciplinary thought and the exposure to different design disciplines is currently used in the College of Architecture and Urban Studies. The prime example is that the first year design studio is a conglomerate of all the different design disciplines.

These next concepts are adapted from the Virginia Tech School of Architecture's studio policy. This method of thinking and interaction with other students is applicable to the mindset that students should have towards a multidisciplinary project and approach to teaching and learning. The multi-disciplined team has a responsibility to contribute to making the laboratory an environment that is respectful of individuals, shares in the intellectual life of the school, and is conducive to disciplined work where multiple facets of education combine. Students should develop a sense of self-reliance and independence; to discipline themselves towards diligence in their working habits; to give full attention to the quality of their work; and to adapt to different lab environments. It expects its students to maintain an open attitude to constructive criticism and advice (VTSOA, 2012). This last part is central to a multidisciplinary approach to learning, without the evaluate criticism from others the project or group cannot function.

After the first year however, all the different disciplines specialize further, separating into each core curriculum. While overall the separation is a factor of logistics and providing more direct learning of material, there could be opportunities to still learn from continued collaboration. Therefore, while secondary classes could remain specialized, a multidisciplinary approach could once again be applied to the studio environment. In this specific case, the studio would be a structure with vegetated facades.

These interdisciplinary programs have the potential to expose students to new methods of thinking that are not always present in disciplinary environments. By combining an interdisciplinary program with a disciplinary program where appropriate, new potential can be made for advances in learning and research. The different scales that interdisciplinary thinking and implementation can occur, make it useful; however new programs need to be adequately supported in order to achieve success. Therefore these different scales of learning all need directed support and curriculums in order to teach and sustain knowledge advancement. The potential for interdisciplinary research and teaching to be used in the university setting cannot be overlooked.

Teaching Philosophy

The mindset of a professor should be to create a learning environment that is an adventure for the students. Learning should be a journey, not simply a list of requirements or work. This adventure allows anything to become a teachable moment, and these movements can last a lifetime.

This mindset is created by the fusion of the opportunities a professor brings to the studio and to the research. Teaching and research are not separate entities, but two methods of distilling information and then returning this knowledge to an audience. A professor is truly successful when the conducted research informs the information passed on to the students. This method of prepared balance must be brought to the academic realm, to maintain the dialogue that teaching has with research.

Through this balanced approach of involving research in the studio, students can realize that their degree was not only an investment in their future, but also an investment in their personal growth and maturity as scholars and professionals. We as educators must cultivate the ability for a student to be intrinsically motivated, while under extrinsic pressures. This interaction then creates a massive change in outlook, in ideals, and in learning capabilities in students.

Students all learn in different manners and it is crucial to understand how to be flexible in meeting their professional and academic needs. It is the actions taken as academics to nurture this potential in our students, which helps them see their own worth; however, this is not a one-way relationship. For everything within the discipline that a professor casts light on, a student also can bring a spark of interest to a new way of thinking that cannot and should not be ignored.

I, as a future faculty member, have the responsibility to create a learning environment that allows for the pursuit of life-long learning, that it would foster a set of conditions that allow students to develop and critically analyze their own aesthetic of architecture. This mindset is created by providing adequate time and space to the students. With adequate time, space and careful guidance in the form of desk critiques and group discussions, students can develop a sense of agency and learn to develop proper representation, writing, discussion, and modeling skills. I used this model as a means of engaging with students as a teaching assistant in a third year studio. These critiques and presentations are not a final conclusion to the development of their architecture, but a point of reference to continue further investigation and exploration. These discussions form the base for how to conduct the studio and are where collaboration can occur between students to further creativity.

In architecture, the past, present and future must be present in the mind of the student as a continuum when developing a prompt or studio project. This is not to say that the student is solely focused in the past, but rather is aware of the past, the past that has become the present and is projected into the future. It is important to understand that this style of architecture is not reactionary, but a combination of natural and man-made stimuli to create space as a designed response. Therefore, the designed response is not an act that is applied to a particular project, but a habit that is maintained by the student, ingrained into the design process. When a method is central to the design from the beginning, the response is stronger and more developed. By viewing their architecture as a continuum, students can

build on past experiences to inform current and future actions. Design and architecture is not a place where simple regurgitation of information will suffice, students will need to critically investigate and iterate designs repetitively. I provide guidance, but foster an environment in which students can guide their own learning by being critically engaged with the material and their peers.

When students are engaged with the material they should do so at multiple scales of interaction, not only in drawing but also in making. I firmly believe that a student's understand of architecture hinges on being able to visualize space in only in representation but also in full-scale construction. My interest in full-scale implementation of design and the critical thinking that this requires is central to my teaching and design philosophy. My experiences leading studio discussions and design-build projects have allowed me to investigate the different learning styles of students and develop methods for engaging students in a respectful manner and seek their involvement in discussions and critiques. This allows students to view their pursuit of architecture in a larger context, to represent their work, to respectfully interact with colleagues, and to develop themselves for professional and academic life-long learning.

Definitions

Plant Characteristic definitions or explanations - PLANTS Database NRCS

These definitions or explanations are in the order in which they appear in the characteristic list and are the definitions used by NRCS.

Morphology - the branch of biology dealing with the form and structure of organisms.

Physiology - the branch of biology dealing with the functions and activities of living organisms and their parts, including all physical and chemical processes.

Active growth period - plants have their most active growth in which seasonal period

Fall conspicuous - Are the leaves or fruits conspicuous during autumn from a landscaping aesthetics? standpoint

Flower color - predominant color of the flowers

Flower conspicuous - Are the flowers conspicuous from a landscaping aesthetics standpoint?

Foliage color - the predominant color of the foliage

Foliage porosity summer - How porous is the foliage during the summer months?

Foliage porosity winter - How porous is the foliage during the winter months?

Foliage texture - What is the general texture of the plant's foliage relative to other species with the same growth habit?

Fruit/seed color - What is the predominant and conspicuous color of the mature fruit or seed from a landscaping aesthetics standpoint?

Fruit/seed conspicuous - Is the fruit or seed conspicuous from a landscaping aesthetics standpoint?

Growth form - What is the primary growth form on the landscape in relation to soil stabilization on slopes and stream sides? Each plant species is assigned the single growth form that most enhances its ability to stabilize soil.

Allelopath - Has this plant species been shown to be allelopathic to at least one other species? Does the plant suppress the of growth of one plant species by another due to the release of toxic substances

Leaf retention - Does the tree, shrub, or sub-shrub retain its leaves year round?

Lifespan - What is the expected lifespan (in years) of a perennial plant relative to other species with the same growth habit?

Shape and orientation - What is the growth form or predominant shape of an individual plant? (This characteristic is especially useful for selecting species for windbreaks.)

Toxicity - What is the relative toxicity of the plant to either humans or livestock?

Soil types - Can this plant establish and grow in a particular soil textured surface layer?

Drought tolerance - What is the relative tolerance of the plant to drought conditions compared to other species with the same growth habit from the same geographical region?

Fertility requirements - What relative level of nutrition (N, P, K) is required for normal growth and development?

Frost free days - The minimum average number of frost-free days within the plant's known geographical range to grow.

Hedge tolerance - What is the relative tolerance of woody perennials to hedging (close cropping) by livestock or wildlife? Herbaceous plants are scored "None" here by default.

Maximum and minimum soil pH - The minimum or maximum soil pH, of the top 12 inches of soil, within the plant's known geographical range.

Planting density - Recommended number of individual plants to plant per acre.

Precipitation (minimum or maximum) - tolerable rainfall (in inches), expressed as the average annual minimum precipitation that occurs 20% of the time (i.e., the probability of it being this dry in any given year is 20%) at the driest climate station within the known geographical range of the plant.

Shade tolerance - What is the relative tolerance to shade conditions?

Bloom period - During what seasonal period in the U.S. does the plant bloom the most? The bloom period is defined as the time when pollen is shed and stigmas are receptive.

Commercial availability - What is the availability of plant propagules in the commercial marketplace?

Fruit/seed abundance, and periods - What is the amount of seed produced by the plant compared to other species with the same growth habit?

Method of propagation - the spreading of something (as a belief) abroad or into new regions

Seedling vigor - What is the expected seedling survival percentage of the plant compared to other species with the same growth habit?

Vegetative spread rate - At what rate can this plant spread compared to other species with the same growth habit?

Attributions of Figures and Tables

Tables

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Location: Blacksburg, VA **Year:** 2014

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Identification: Working List of Plants for use in Dissertation

Location: Blacksburg, VA **Year:** 2014

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Identification: Experience and Method in Vegetated and Living Walls Sample Method

Location: Blacksburg, VA **Year:** 2014

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Table 4: Photographer/Creator: Kenneth Black

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Identification: observation of the electric car garage note sheet

Location: Blacksburg, VA **Year:** 2014

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Identification: tactics for use in studio environment

Location: Blacksburg, VA **Year:** 2014

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Identification: tactics for reducing data and coding to find meaning in journals and books

Location: Blacksburg, VA **Year:** 2014

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Identification: tactics for testing the teaching method and prototype tool

Location: Blacksburg, VA **Year:** 2014

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Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Proscriptive and Prescriptive Methods to influence the prototype tool

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 2: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Placement of Prototype tool in the design process

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 3: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: All themes in reference to ideation, representation and iteration

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 4: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: carport under construction

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 5: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: simplified overview of qualitative method for dissertation

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 6: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: blue/orange poplar watercolor

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 7: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: diagram about ideation, representation and iteration

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 8: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Two watercolor studies of superposition using the compliments of orange and blue

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 9: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: transparency in color off of Albers' work

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 10: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: figure-ground examples

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 11: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: figure-ground examples: overlapping planes

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 12: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: pigment mixtures of blue, orange and black

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 13: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: color mixing RGB and CMYK

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 14: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: traditional color pairings

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 15: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: example of partitive mixing

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 16: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: color spectrum index numbers by multiples of 10 of red and green

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 17: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: three hues of red with no background

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 18: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: three hues of red with a fourth hue background

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 19: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: all four examples of the tiled image of Frank Lloyd Wright

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 20: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: color tiled image of Frank Lloyd Wright

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 21: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: black and white tiled image of Frank Lloyd Wright

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 22: Photographer/Creator: REX

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Hanging Gardens of Babylon

Location: wikimedia **Year:** 2005

Copyright Restrictions: Author died more than 100 years ago public domain images, CC-PD-Mark, Engravings of buildings
http://upload.wikimedia.org/wikipedia/commons/a/ae/Hanging_Gardens_of_Babylon.jpg

Figure 23: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: vegetated tower in Davis CA

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 24: Photographer/Creator: USDA, ARS, OSU

Contact Info: PRISM Climate Group, Oregon State University

Copyright Holder: USDA

Identification: USDA Agricultural Research Service US hardiness zone map.

Location: wikimedia **Year:** 2012

Copyright Restrictions: good, cite OSU and ARS

Figure 25: Photographer/Creator: USDA, ARS, OSU

Contact Info: PRISM Climate Group, Oregon State University

Copyright Holder: USDA

Identification: Virginia USDA Agricultural Research Service US hardiness zone map.

Location: wikimedia **Year:** 2012

Copyright Restrictions: Need Permission, permission pending

Figure 26: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: method for generating the literature based short list of plants

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 27: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Virginia creeper at RDF

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 28: Photographer/Creator: USDA, ARS, OSU

Contact Info: PRISM Climate Group, Oregon State University

Copyright Holder: USDA

Identification: USDA Agricultural Research Service US hardiness zone map.

Location: wikimedia **Year:** 2012

Copyright Restrictions: good, cite OSU and ARS

Figure 29: Photographer/Creator: USDA, ARS, OSU

Contact Info: Virginia Nursery and Landscape Association

Copyright Holder: VNLA

Identification: VNLA list of vines for Virginia

Location: 2013 Virginia Growers Guide **Year:** 2013

Copyright Restrictions: personal photocopy of the list

Figure 30: Found: http://commons.wikimedia.org/wiki/File:Green_wall_Paris.jpg

Photographer: Ryan Kaldari

Contact Info: http://commons.wikimedia.org/wiki/User:Kaldari

Copyright Holder: Ryan Kaldari

Identification: A green walled building in Paris, France (Quai Branly Museum)

Location: Paris, France **Year:** 2009

Copyright Restrictions: This file is made available under the Creative Commons CC0 1.0 Universal Public Domain Dedication. The person who associated a work with this deed has dedicated the work to the public domain by waiving all of his or her rights to the work worldwide under copyright law, including all related and neighboring rights, to the extent allowed by law. You can copy, modify, distribute and perform the work, even for commercial purposes, all without asking permission.

Figure 31-37 Photographer: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Photos around Blacksburg

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken as Photographer

Figure 38: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: theory map for design method

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 39: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: inputs to ideation for dissertation

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 40: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: triangulation of previous theories for the prototype tool

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 41: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: decision theory in reference to decision support for vegetated assemlies

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 42: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: full design support structure framework

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 43: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: framework criteria for use in the prototype tool

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 44: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: initial plan and section of the carport

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 45: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: carport under construction

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 46: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: sketch of the vegetated wall for he carport

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 47: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: current as-is process for the implementation of the prototype tool

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 48: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: vegetated roof on a lookout

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 49: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: geometric abstraction of plan and vegetation proportioning

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 50: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: plan, section, elevation in relation to direct applied vegetation

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 51: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: set of sketches in pre-design exploring how to implement vegetation

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 52: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: mapping interpretivism and tactics for use in evaluating as-is structures

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 53: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: studio elements for implementation

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Figure 54: Photographer/Creator: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: initial tool interface map for alpha testing

Location: Blacksburg, VA **Year:** 2014

Copyright Restrictions: None, Cite Ken

Images in Appendices:

Figure A-C

Photographer: Kenneth Black

Contact Info: kenblack@vt.edu

Copyright Holder: Kenneth Black

Identification: Photos of trip to Biosphere 2

Location: Oracle, AZ **Year:** 2014

Copyright Restrictions: None, Cite Ken as Photographer

5

Bibliography + Endnotes

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Endnotes

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[i] But where did Blanc's vegetated wall come from? Blanc tells a story of how the vertical garden started as a home waterfall, and then by adding a sealed wooden plank, this allowed a variety of plants to survive. His vertical gardens evolved not through experimentation but through mimicking environments through observation by immersion in nature. His walls mimic the natural habitats he uses: waterfalls, riverbanks, seeping rocks, cliffs/karsts, rocky outcrops, caves and dark glens, forest understory, and slopes (Blanc & Lalot, 2011). He uses these natural systems to inform his implementation of an adapted vegetated wall and takes the conditions present at each to instill that sense of awe that nature inherently creates. Not every iteration of a theme is completely successful and lessons are learned for future investigations. Some of the plants that were added survived others did not based on the living conditions the first vegetated wall provided. After installing the vegetated wall the aquarium water below changed in pH levels, turned a 'tea' color and was unpleasant. The deposition layer, which is a few millimeters thick in natural waterfall environments, needed to be developed and was accomplished with a cotton fiber mat. Since cotton fibers naturally decay that mat became synthetic so that it would not rot. One critical attribute though was the supply of water. In later iterations automatic watering was used to prevent the roots from drying out. This first garden is 25 years old and continues to thrive (Blanc & Lalot, 2011). All of these observations would further develop the vegetated wall.

His implementation of the vegetated walls has become more sophisticated over time. These plants, controlled by the assembly form an air buffer of PVC, irrigation cloth and plants, combined with rigid panels for additional support of expanded PVC. Since the weight of added structures of the wall can accumulate quickly, the cloth layer instead of soil weighs less and can be implemented on smaller

structures (Blanc & Lalot, 2011). This is an example of how natural systems can be mimicked by artificial means. This synthetic cloth layer acts like the thin film layer of algae or moss as found in nature, providing the substrate for the entire assembly. The cloth allows plants to root into the layer and then grow in any manner only restricted by the edges of the cloth and vegetated wall assembly. By having the base, the substrates for which plant life can be mimicked all exchange for the life of plant is at the irrigation cloth. This includes the microorganisms and oxygenation required for healthy plant growth (Blanc & Lalot, 2011). With the development of the vegetated wall determined, the next step is to implement plants based on the site. The designer needs to know the geographic location, latitude and cardinal direction to determine the climate of the wall and then respond accordingly. This type of responsive architecture is critical to the implementation of vegetated walls. Furthermore, with the exact wall in mind, a composition can be formed on the wall. For example, Blanc used shrubs in the top, herbaceous in the bottom, the reverse of normal to allow space where people are: at the street level (Blanc & Lalot, 2011). This juxtaposition of species gives depth on the seeming flat surface of the wall. The wall then can become a living organism that needs to be cultivated and grown. Now the constructed environment is not a hindrance but an addition, a substrate for the diversity that plants can provide.

[ii] Some species use chemical adhesives to adhere directly to walls, for example Virginia Creeper (Ampelopsis and Parthenocissus). Some growths are superficial growth such as mosses and algae. Others are a more hazardous growth such as smaller ficus, some halophyte plants, and bellflowers growing between stone. Destructive roots of larger plants move in between the stone and have worked them apart, for example the full scale Ficus religiosa (Blanc & Lalot, 2011).

[iii] As with more recent work with Blanc, observations have found that walls must have a constant or useful source of water, thus retaining walls are a common location for plants. This is due to the soil on the backside of the wall serving as a water source. However, a south facing wall gain much more radiation and can dry out more, whereas north facing walls are cooler and can have more moss. The plants that could live on the south wall are more luxuriant on the north wall. Orientation, shade, insulation, wind, water, construction, color slope, thickness of walls, climate macro and micro, accumulation of sediment, wall type and material determine plant species and growth (Laurie, 1979).