Title
Information Systems for Grassroots Sustainable Agriculture

Author
Norton, Juliet

Publication Date
2019

UNIVERSITY OF CALIFORNIA,
IRVINE

Information Systems for Grassroots Sustainable Agriculture

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Informatics

by

Juliet Nicole Pumphrey Norton

Dissertation Committee:
Professor Bill Tomlinson, Chair
Professor Bonnie Nardi
Professor Donald J. Patterson
Assistant Professor Josh Tanenbaum

2019

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GLOSSARY

Action Research	A form of collaborative research in partnership with community members to improve a situation (Adelman 1993; Lewin 1946).
Activist Research	A form of collaborative research in partnership with powerless communities in their process of pursuing some form of social change that equalizes the status quo (Cancian 1993).
Agroecology	An agriculture practice and scientific field that applies ecology to agriculture (Lovell 2012), integrates modern and traditional knowledge of agriculture systems, integrates social science and natural science, and emphasizes food sovereignty and social and biological diversity (Cleveland 2014).
Agroecosystems	Sites or integrated regions of agriculture production understood as an ecosystem (Gliessman 2015). An agroecosystem is equivalent in organization to "a hierarchy ascending from the level of the individual plant or animal all the way to national systems linked by international trade" (Conway and Barbier 1988, 651).
Community of Practice	"Formed communities that share cultural practices and reflect their collective learning" (Wenger 2000, 229). Members of a community of practice know each other and use similar language, routines, and tools in context of forming and contributing to the community.
Database	A collection of interrelated data stored and organized in a computer's external memory so that users can easily access, manage, and update the information (Poljak, Poščić, and Jakšić 2017). Information stored in a database can be searched and organized according to filters designated by a user.
Ethnobotany	The study of how all humans use or used plants in their local contexts (Cotton 1996).
Grassroots Agroecology	Agroecology as practiced by ordinary people, not researchers or professionals.

Grassroots Sustainable Agriculture	Sustainable agriculture as practiced by ordinary people, not researchers or professionals. Grassroots Agroecology is one form of Grassroots Sustainable Agriculture.
Homegrown Crowd	A self-assembled group of members from a community that do work for their community.
Human Computer Interaction (HCI)	The study of the way in which computer technology influences human work and activities (Dix 2009).
Information Ecology	A location-specific "complex system of parts and relationships with a focal point on human activities that are served by technology" (Nardi and O'Day 2000, 50).
Permaculture	A design ideology and associated social movement. As a design ideology and social movement, permaculture aims to "integrate landscape and people to provide for their own food, energy, shelter, and other material and non-material needs in a sustainable way" (Mollison 1988, xi).
Permaculture Systems	A coupled human and natural system in which agriculture and/or ecology underpin human activity.
Permie	A person whom identifies as a participating member of the permaculture social movement.
Plant Database	A collection of interrelated plant data stored and organized so that users can easily access, manage, and update the information.
Plant Document Database	In this context, a plant document database is a collection of static documents containing plant information that users can read. The documents are searchable by tags (e.g., plant names), but the content within the document is not searchable nor organizable by database queries.
Plant Information Resource	Any kind of information resource about plants including databases, blogs, and publication libraries.
SAGE	**S**oftware for **Ag**ricultural **E**cosystems. The collection of software applications presented in this dissertation to support the public pursuit of sustainable agriculture.
SAGE Plant Database	A searchable database of plants used for grassroots or amateur agroecology design, including ethnobotanical, cultivation, morphological, and phenological data for each plant.

Social Movement	An informal network of people who are aligned in their engagement in a political or cultural conflict and share a collective identity (Diani 1992). People who identify as members of a social movement participate individually or in small groups in activities characteristic of the movement and work towards addressing the conflict.
Sustainable Agriculture	A term that defies definition (Gold 2007). However, most definitions include the ideas that sustainable agriculture is an intertwined natural and human system (Cleveland 2014; FAO 2014, 12–13; Gliessman 2015; Mollison 1988; Council 2010, 221); and a "sustainable" agricultural system should maximize environmental, social, and economic factors in addition to the goal of feeding people.
Sustainable Polyculture	An assemblage of complementary and mutually beneficial plant species, typically composed primarily of perennials, used by the Permaculture communities as a food and other provision-producing construct.
Technology Steward	A person who understands the community's technology needs, has enough experience with technology, and would like to take leadership in addressing those needs (Wenger, White, and Smith 2009).

ACKNOWLEDGEMENTS

I would like to begin by thanking my committee for their guidance, encouragement, and feedback during this research. Bill Tomlinson, Bonnie Nardi, Josh Tanenbaum, and Don Patterson – thank you for helping shape this research and this dissertation into something I am proud to present to the world. I would also like to thank other faculty at UCI and UCF for their support in recent and distant times, respectively: André van der Hoek, Melissa Mazmanian, Debra Richardson, Joe LaViola, Eileen Smith, and Charles Hughes.

This research could not exist without the following participating activists and organizations: Tia Silvasy, Tina Richards, Alex Stringfellow, Simple Living Institute, The Ecology Center, Peter Bowler, UCI Arboretum, UCF Arboretum, Orange County Outdoor Education Center, and Patty Hemphill. Each of you have inspired me with your desire to make the world a better place.

I would like to thank my colleagues and dear friends, Ankita Raturi and Birgit Penzenstadler, for their council, collaboration, and moral support. I missed you both when you left UCI, but we have remained friends and collaborators. I am beyond excited to continue this trend. I'd like to thank my other graduate student friends, Neil Young, M. Six Silberman, Sam McDonald, Amy Hoover, Sarah Buchanan, Marcel Pufal and Xinning "Sunny" Gui, many of whom are now graduated, for helping with my research, for also sharing yours, and, of course, providing opportunity for laughter. I would also like to thank all of the UCI students who assisted in the implementation and reporting of this project: Xin Hu, Daniel McInnis, Moin Aminnaseri, Sahand Nayabaziz, Kristen Segismundo, Vishal Sharma, Anita Marie Tassan, Parker Scott, Katarina Michel, and Maruf Zaber.

Thank you to my local support network – I could not have survived grad school without your help and friendship: Chelsea, Jonathan, Quinn and Lila Sutton, Deirdre O'Reilly, Matt Dean, and Onóra Dean-O'Reilly, Ngoshali Haulenga, Wyatt and Esther Clarke, and Karen Tanenbaum. Finally, thank you to my family for sticking with me through this long journey: my parents Bill and Sharon, my sisters Jenni and Jessica, my brother-in-laws Randy and Steve, my nieces Zephyr and Loris, my nephew Soren, and my daughter Aurora.

This material is based in part on work supported by the NSF under Grants No. CCF-1442749 and IIS-0644415.

CURRICULUM VITAE

Juliet N. P. Norton

EDUCATION

Doctor of Philosophy in Informatics **2019**
University of California, Irvine

Master of Science in Computer Science **2010**
University of Central Florida

Bachelor of Arts in Digital Media **2007**
University of Central Florida

RESEARCH APPOINTMENTS

Graduate Research Assistant	Social Code Group, University of California, Irvine	**2013-2019**
Research Staff	Social Code Group, University of California, Irvine	**2013**
Graduate Research Assistant	ISUE Lab, University of Central Florida	**2009-2013**
Graduate Research Assistant	SREAL and E2i, University of Central Florida	**2008-2009**
Research Staff	MCL (now E2i), University of Central Florida	**2007-2008**

RESEARCH EXPERIENCE

University of California, Irvine

Dissertation: Information Systems for Grassroots Sustainable Agriculture **2015-2019**

I studied the practices, values, and information challenges two grassroots sustainable agriculture communities and worked with them to develop a database that supports their practices and values and addresses a subset of their information challenges. This research is a subset of the work being done for the NSF CyberSEES project, listed below. My responsibilities include project management, system design, interaction design, development.

NSF CyberSEES: Fostering Non-Expert Creation of Sustainable Polycultures **2015-2018**
through Crowdsourced Data Synthesis.

SAGE is the manifestation of the collection of software tools being built for the NSF CyberSEES awarded project titled *Fostering Non-Expert Creation of Sustainable Polycultures through Crowdsourced Data Synthesis*. My responsibilities include project management, participatory observation of grassroots sustainable agriculture movements, requirements engineering, system design, interaction design, and development. I managed a team of ten students and graduates for this project.

Plant Guild Composer **2011-2014**

The Plant Guild Composer is an early manifestation of one of the pivotal applications in the SAGE framework and was the mechanism by which the SAGE project was imagined. My responsibilities included management, participatory observation of grassroots sustainable agriculture movements, prototype development. I managed five undergraduates for this project. This work has been published at CHI Interactivity in 2014, the RE workshop for Sustainable Systems in 2013 and the CHI Simple, Sustainable Living workshop in 2012.

University of Central Florida

NSF Creative IT: Minds of Chimera and Lunar Quest CLEM **2009-2012**

Lunar Quest CLEM was a Multiverse MMORPG for teaching physics concepts via constructing physics experiments in game. Minds of Chimera was a collection of STEM education activities built as mods in Minecraft. My responsibilities included educational content delivery design, game play design, development. Managed a team of three undergraduates for both projects. This work has been published as a CHI work-in-progress and a CHI Extended Abstract in 2012.

NSF DRL: Water's Journey Through the Everglades **2007-2009**

This project involved the development of 10 kiosks that explored ecological change in the Florida Everglades and associated systems. The kiosks are on display at the Museum of Discovery and Science in Ft. Lauderdale, FL. My responsibilities included content research and experience design; lead developer of kiosk that simulated human encroachment on native fauna; focus group facilitator; and experiment moderator for iterative design studies.

Exploring Full Body Navigation Interfaces **2009-2010**

This study explored how participants might naturally use only their body to direct an avatar though a virtual environment. Using wizard-of-oz methodology I navigated participants through the virtual environments in the popular game *Mirror's Edge* according to their physical actions. My other responsibilities included study design, recruitment, and facilitation; building information tools to capture data; and data analysis. This research was published at Foundations of Digital Games in 2010 and presented as a poster in the ACM Student Research Competition at Grace Hopper Celebration in 2010.

NIH AREA: Using Mixed Reality to Build Peer Resistance Skills in Latina Middle Schoolers **2008, 2012**

This project entailed the development of a game called Drama-Rama that provides children and adolescents opportunities to practice resisting peer pressure. My responsibilities included focus group facilitator and experiment moderator.

RDECOM: M4 **2009**

M4 was the fourth iteration of MR MOUT, a testbed for military training simulations in the context of urban terrain. My responsibilities included story flow and situational awareness design for both projects; integrating all assets into our MR engine; assisting in experiment design; assisting in experiment facilitation.

Virtual Reality Medical Center (VRMC): MR Warehouse **2008**

MR Restaurant was a proof of concept for the technical feasibility of the MR environment designed to measure the affective response of persons who stutter when presented with an everyday life experience. My responsibilities included asset creation, integrating asset into our MR engine, and experiment moderation.

RDECOM: Lunar Lunge **2007**

Lunar Lunge was a youth-friendly experience built on the MR MOUT testbed to understand more about the next-generation talent that will be using emerging MR technology. My responsibilities included story flow and situational awareness design for both projects; establishing a production pipeline; integrating all assets into our MR engine; supplemental 3D modeling; assisting in experiment design; assisting in experiment facilitation; and assisting in data analysis.

VRMC: Smash Me **2007**

Smash Me was a proof of concept of the technical feasibility of the MR environment as a physical rehabilitation tool for patients needing upper body extremity rehabilitation, whether from a stroke or other impairment. My responsibilities included asset creation, integrating asset into our MR engine, and experiment moderation.

VRMC: MR Restaurant **2007**

MR Warehouse was a proof of concept for the technical feasibility of the MR environment to capture and analyze requested data in support of creating an assessment tool for soldiers suffering from traumatic brain injury (TBI). My responsibilities included asset creation, integrating asset into our MR engine, and experiment moderation.

PUBLICATIONS

Conference Proceedings

C7. Barath Raghavan, Bonnie Nardi, Sarah T. Lovell, **Juliet Norton**, Bill Tomlinson, and Donald J. Patterson. Computational Agroecology: Sustainable Food Ecosystem Design. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pp. 423-435. ACM, 2016.

C6. Bill Tomlinson, **Juliet Norton**, Eric PS Baumer, Marcel Pufal, and Barath Raghavan. Self-obviating systems and their application to sustainability. *iConference 2015 Proceedings* (2015).

C5. Birgit Penzenstadler, Bill Tomlinson, Eric Baumer, Marcel Pufal, Ankita Raturi, Debra Richardson, Baki Cakici **et al.** ICT4S 2029: What will be the systems supporting sustainability in 15 years. In *Proceedings of the 2014 conference ICT for Sustainability*, vol. 2, pp. 30-39. Atlantis Press, 2014.

C4. Eric PS Baumer, June Ahn, Mei Bie, Elizabeth M. Bonsignore, Ahmet Börütecene, Oğuz Turan Buruk, Tamara Clegg **et al.** CHI 2039: speculative research visions. In *Proceedings of the 2014 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '14), pp. 761-770. ACM, 2014.

C3. **Juliet Norton**, Alex J. Stringfellow, Joseph J. LaViola Jr., Birgit Penzenstadler and Bill Tomlinson, Plant Guild Composer: A Software System for Sustainability. In: Proceedings of the 2nd International Workshop on Requirements Engineering for Sustainability (RE4SuSy). Rio, Brazil, July 15, 2013, CEUR-WS.org, online at CEUR-WS.org/Vol-995.

C2. Chadwick Wingrave**, Juliet Norton**, Christopher Ross, Nathan Ochoa, Sergiu Veazanchin, Emiko Charbonneau, and Joseph LaViola. 2012. Inspiring creative constructivist play. In *Proceedings of the 2012 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '12). ACM, New York, NY, USA, 2339-2344.

C1. **Juliet Norton**, Chadwick A. Wingrave, and Joseph J. LaViola, Exploring Strategies and Guidelines for Developing Full Body Video Game Interfaces. In *Proceedings of the Fifth International Conference on the Foundations of Digital Games* (FDG '10). Monterey, California, June 19-21, 2010. ACM, New York, NY, 155-162.

Workshop Papers and Posters

W5. Ankita Raturi, **Juliet Norton,** Bill Tomlinson, Eli Blevis, and Lynn Dombrowski, Designing Sustainable Food Systems. 2017. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pp. 609-616. ACM, 2017.

W4. **Juliet Norton**, Accounting for Potentially Detrimental Unintended Impacts in HCI. 2014. In *Proceedings of What have we learned? A SIGGCHI HCI & Sustainability Community Workshop.* At ACM CHI 2014 Conference on Human Factors in Computing Systems. Toronto, CA.

W3. **Juliet Norton**, Alex J. Stringfellow and Joseph J. LaViola Jr., Domestic Plant Guilds: A Novel Application for Sustainable HCI. 2012. In *Proceedings of Simple, Sustainable Living Workshop.* At ACM CHI 2012 Conference on Human Factors in Computing Systems. Austin, TX. 4 pages.

W2. Chadwick Wingrave, **Juliet Norton**, and Joseph J. LaViola Jr., Using Minecraft for Instruction and Creative Play. 2012. In ACM CHI 2012 Conference on Human Factors in Computing Systems, Educational Interfaces, Software, and Tech Workshop. Austin, TX. 4 pages.

W1. **Juliet Norton**, An Exploration of Intuitive Travel Techniques for Full Body Video Game Interfaces. 2010. Presented at the ACM Student Research Competition at Grace Hopper Celebration of Computing. Atlanta, GA. Poster.

Magazines

M3. **Juliet Norton**, Ankita Raturi, Bonnie Nardi, Sebastian Prost, Samantha McDonald, Daniel Pargman, Oliver Bates, Maria Normark, Bill Tomlinson, Nico Herbig, Lynn Dombrowski. 2017. A Grand Challenge for HCI: Food + Sustainability. In *interactions* , 24, 6, (November 2017), 50-55.

M2. Birgit Penzenstadler, Ankita Rauturi, Christoph Becker, **Juliet Norton**, Bill Tomlinson, Six Silberman, and Debra Richardson. 2015. Bridging communities: ICT4Sustainability @ iConference 2015. In *interactions* 23, 1 (December 2015), 64-67.

M1. Bill Tomlinson, Donald Patterson, Yue Pan, Eli Blevis, Bonnie Nardi, Six Silberman, **Juliet Norton**, Joseph LaViola Jr. 2012. What if Sustainability Doesn't Work Out? In: *interactions* 19, 6, (November 2012), 50-55.

MENTORSHIPS

Informal	University of California, Irvine. Mentored Jason Huang and Matthew Nguyen on component of NSF CyberSEES project.	**Summer 2018**
Independent Study INF 199	University of California, Irvine. Mentoring Xin Hu on a component of the NSF CyberSEES project.	**Spring 2016**
Informal	University of California, Irvine. Mentoring Katarina Michel on educational and develop programs at the UCI Permaculture Research Area in the UCI Arboretum.	**Fall 2016 – Spring 2017**
Independent Study INF 199	University of California, Irvine. Mentoring Xin Hu, Daniel McInnis, and Kevin Li on various components of the NSF CyberSEES project.	**Fall 2016**
SURF IoT	University of California, Irvine. *SURF IoT* – Co-mentored Xin Hu in datamining social media for plant data research.	**Summer 2016**
Independent Study INF 199	University of California, Irvine. Mentored Sahand Nayabaziz and Dinorah Carrion in early investigations of information systems for sustainable agriculture research.	**Fall 2013**
Independent Study INF 199	University of California, Irvine. Mentored Sahand Nayabaziz, Sean Burke, Dinorah Carrion, B. Jack Pan, and Anna Slykhous in early investigations of information systems for sustainable agriculture research.	**Winter – Spring 2013**

L.E.A.R.N	University of Central Florida. Mentored a freshman in computer science games research	**Fall 2011 – Spring 2012**
Workforce Central Florida	University of Central Florida. Mentored a freshman in an original Computer Science research project.	**Fall 2012**

TEACHING EXPERIENCE

Instructor of Record	*Global Disruption and Information Technology-* University of California, Irvine Online UC-Wide course of 170 students.	**2018**
Graduate Teaching Assistant	*Global Disruption and Information Technology-* University of California, Irvine Online UC-Wide course of 223 students. Primary TA for 73 students across 4 Discussion Groups.	**2016**
Graduate Teaching Assistant	*Organizations and Information Systems-* University of California, Irvine Writing class. Recitation instructor for one 50-minute section of 40 students that focused on written assignments.	**2014**
Course Designer	*Global Disruption and Information Technology-* University of California, Irvine Member of design team for online UC-Wide course.	**2014**
Graduate Teaching Assistant	*Environmental Issues in Information Technology-* University of California, Irvine TA for approximately 110 students. No recitation.	**2013**
Graduate Teaching Assistant	*Concepts in Computer Science-* University of Central Florida	**2012**

	Recitation instructor for two 50-minute sections of 25 students each.	
Graduate Teaching Assistant	*Burnett Honors College Summer Institute-* University of Central Florida Recitation instructor for 3-week computer science summer camp for high school students.	**2011**

TRAINING AND OTHER EDUCATION

Preparing Tomorrow's Faculty Program, UCF **2012**
Engaged in 10-week training to design courses and teach at the university level. Produced a first draft of a teaching portfolio.

Plant Pathology, Valencia College, Orlando, FL **2011**
An undergraduate semester course in the Horticulture and Technology Department

Intro to Horticulture, Valencia College, Orlando, FL **2011**
An undergraduate semester course in the Horticulture and Technology Department

Permaculture Design Certification, Simple Living Institute, Orlando, Florida **2011**

GUEST LECTURES

Reimagining the Suburban Landscape **Spring 2014**
Class: Urban Sociology (PPD 40),
University of California, Irvine

Plant Guild Composer: Applying your profession to what you care about **Fall 2013**
Class: Environmental Issues and Information Technology (ICS 5),
University of California, Irvine

Plant Guild Composer: An IT solution for sustainable agriculture design **Winter 2013**
Class: Environmental Issues and Information Technology (ICS 5),
University of California, Irvine

The Plant Guild Composer and local food security in UCI communities **Spring 2013**
Event: Gather Lunch, Environment Institute,
University of California, Irvine

PROFESSIONAL SERVICE

Gathering of Open Agriculture Technology (GOAT) – Co-organizer	**2018-2019**
Biddy GOAT at USDA ARS – Co-organizer	**2018-2019**
iConference – Student Volunteer (SV)	**2019**
Workshop on Long(er) Term Design Thinking – Methods demo	**2018**
Designing Sustainable Food Systems Workshop – Co-organizer	**2017**
Mind, Culture, and Activity – Paper Reviewer	**2016**
CHI 2017– Paper Reviewer	**2016-2017**
CHI 2016– Paper Reviewer	**2015-2016**
ICT4S – Paper Reviewer	**2014**
CHI 2014 – SV	**2014**
IEEE VR – Interim SV Chair	**2013**
Joint Virtual Reality Conference of EuroVR – Paper Reviewer	**2012**
Grace Hopper Celebration of Women in Computing – SV	**2009**

AWARDED GRANTS

UCI The Green Initiative Fund: Wildflowers at the UCI Permaculture Research Area **2017**
Principle Investigators: Katarina Michel, **Juliet Norton**, Bill Tomlinson, Peter Bowler. Awarded Amount: $108.15.

UCI The Green Initiative Fund: Planting Edible Natives **2016**
Principle Investigators: Ezra Monroy, **Juliet Norton**, Bill Tomlinson, Peter Bowler. Awarded Amount: $400.00.

NSF CyberSEES: Fostering Non-Expert Creation of Sustainable Polycultures through Crowdsourced Data Synthesis **2015**
Principle Investigators: Bill Tomlinson, Don Patterson, Sarah Taylor Lovell. **Juliet Norton** made significant contributions to the project concept, proposal writing process, and funded research. Awarded Amount: $398,838.00.

ACADEMIC AWARDS

Graduate Assistance in Areas of National Need (GAANN) Graduate Fellowship. Award Amount: quarterly tuition and stipend. **2016-2019**

UCF Alumni: Graduate Scholarship. Awarded Amount: $1,000. **2012**

UCF CECS: *David T. and Jane McDonaldson Memorial Foundation Scholarship*. Awarded Amount: $2,500. **2011, 2012**

UCF College of Graduate Studies: *Best Poster at UCF Graduate Research Forum*. Awarded Amount: $500. **2010**

COMMUNITY INVOLVEMENT

Sustainability, Human Security, and Gardening

The Ecology Center – Eco Kids Volunteer **2018**

UCI Arboretum Permaculture Research Area – Project coordinator **2015-2018**

California Higher Education Food Summit (C.H.E.F.S.) – Organizer and host for workshop titled "Growing Food in the Neighborhood" **2016**

UCI in Solidarity with Orlando – Co-host of nature walk, reflection, and guided meditation event in the wake of the Pulse Nightclub tragedy in Orlando, FL **2016**

UCI Earth Week – Organizer and Host for workshop series entitled "Planting Edible Natives" **2016**

UCI Campus as a Living Lab: Seed to Plate Workshop Series – Organizer and host of one workshop entitled "Native Food Forests" **2015**

The Ecology Center – Guest Instructor **2015**

The Ecology Center – Secondary facilitator for Eco-Apprentice course **2014**

UCI Food Conference – Co-organizer and panel moderator **2014**

Simple Living Institute - Web Master **2013**

UCF Arboretum - Gardening, design, and management of volunteers **2011-2012**

Econ Farm – Intern for permaculture design and on-site management **2011-2012**

Galileo School for Gifted Learning – Garden facilitation assistant to Anne Schultz of K-5 children **2011**

Winter Park Urban Farm – Volunteer and facilitator assistant to Tia Silvasy in the garden	**2011**

STEM Outreach

CSU-Long Beach - Computing to Change the World for the Better: A Research-focused Workshop for Women – Project Co-coordinator	**2018-2019**
Science Night, Central Florida Coalition for the Homeless – Facilitator of one or more groups of children between ages 3 and 10 in successfully completing that night's science activity	**2010-2012**
Women in EECS, University of Central Florida – President, Public Relations, Member	**2008-2013**
Robots R.O.C.K., A Central Florida EECS Outreach Program – Co-Founder and event organizer	**2011-2012**
Achieve a College Education, University of Central Florida – Facilitator of 30 students in completing activities that exercised programming and algorithm concepts	**2011**
Seminole County Science, Math, and Technology Fair – Judge	**2010-2012**
Mystery Design Workshop, University of Central Florida – Facilitator of two groups of 40 students in completing building activities that address engineering principles	**2010**
College Shadow Day, University of Central Florida – Facilitator of groups of 30 students in completing building activities that address engineering principles	**2009-2010**
Medicine and Technology Internship, Harlem Children's Society – Research mentor of three Harlem high school students visiting for three weeks	**2008**

ABSTRACT OF THE DISSERTATION

Information Systems for Grassroots Sustainable Agriculture

By

Juliet Nicole Pumphrey Norton

Doctor of Philosophy in Information and Computer Sciences

University of California, Irvine, 2019

Professor Bill Tomlinson, Chair

Scientists widely accept that modern agriculture is unsustainable, but the best methods for addressing unsustainability are still contested (Constance, Konefal, and Hatanaka 2018). Grassroots sustainable agriculture communities have long participated in the exploration of solutions for agriculture unsustainability, and their momentum continues to grow in the technical age. Practitioners of grassroots sustainable agriculture use many information systems that were not originally built to support the design of agricultural systems. Based on ethnographic research with two grassroots sustainable agriculture communities, I show that participants' personal and community values frequently clashed with those embedded in information systems, including ones used to look for and manage plant information. Furthermore, I demonstrate a range of information challenges that participants faced in the absence of tools designed to support their specific work. I argue that practitioners of grassroots sustainable agriculture need information

systems tailored to their goals and values in order to productively address barriers to designing and building agroecosystems for their communities.

This dissertation provides an example of how to involve communities in the development of information technology artifacts and strengthen efforts to support sustainability via technological interventions. First, I engaged in two grassroots sustainable agriculture communities as a participant, experiencing their practices, values, and information challenges first hand. Then, I worked with the communities to create a plant database web application (SAGE Plant Database) that supports agroecosystem design in local contexts. Members of the communities participated in the design, development, and data population stages so that the SAGE Plant Database supports their design context and upholds their technological and holistic sustainability values. At the foundation of the database is a plant ontology grounded in the participants' practice of designing agroecosystems. My comparative analysis of the design of the SAGE Plant Database to other databases demonstrates its relevance due to its emphasis on agroecological relationships among plants and between plants and the environment, the inclusion of ethnobotanical data, and the embedded community values. By engaging in this research, I seek to make progress towards transforming the technology-supported food system into one that furthers food security, food sovereignty, and holistic sustainability.

PROLOGUE

This dissertation opens with an illustrative vision of sustainable agriculture in 2045. This vision is a result of a workshop with a sustainable agriculture community that participated in this research (see section 3.2.2). At this workshop, 16 members of a permaculture community described their visions of a possible future.

The following 30-year design future documents environmental, social, and technical contexts and presents SAGE, a suite of information systems for agroecosystem design and management. SAGE represents the long-term values community members would like to see embedded in the technologies that are being designed in the present day.

Figure 0-1 The design future workshop with Manzanita Community in 2015. Photo by Peter Bowler.

A 30-Year Design Future: Manzanita in 2045

It is 2045, and the California drought has lasted for more than 30 years. Conflicts over water rights are prevalent. Environmental water usage, which includes water that flows into rivers, water used to maintain fish and wildlife habitat, water that supports wetlands and preserves, and water needed to maintain water quality, has fallen to 30% from 50% in the 30-year time period. Agriculture in the Central Valley in particular has gained a bad reputation because it accounts for 85% of non-environmental water usage in the state, which equates to more than half of total annual water usage in the state.

During the same period, the nation experienced an economic downturn and income inequality progressed such that the "middle class," which boomed in the 20th Century, has all but been eliminated. There are now only two socioeconomic classes: the minority ultra-wealthy, and the struggling poor. As wealthy tax payers lobbied against subsidizing the cost of water for agriculture, most California farmers lost water rights and thus the nation lost half of its primary fruit and vegetable producers. In the metropolitan area that the Manzanita community resides in, like many other places in the nation, the poor majority feels the strain of food and water insecurity disproportionately greater than the wealthy. The wealthy minority continues to pay exorbitant prices for water and food imported from other places in the world. For some time now, suburban, industrial, and blue-collar towns in the metropolitan area have been sprinkled with abandoned lots and open land from failed businesses and emigration to other parts of the country or world. Gradually, the mindset of the poor majority changed in regard to development and resources, and now an emerging leadership had transformed the vacant spaces into agricultural hubs that support the hosting communities and the nearby, more densely populated urban areas.

The emerging leadership in the metropolitan area grew from the small but strong sustainable agriculture movement, which itself has many different roots, including permaculture in the former middle class, organic community gardens in the Hispanic communities, and home gardeners from people who relocated from places where growing food was a cultural norm. Thirty years ago, in 2015, the roots of the sustainable agriculture movement were disjointed. In the following decade, members of the disjointed communities banded together and sprouted an integrated sustainable agriculture community. One of the ways this partnership was able to occur was through an online sustainable agriculture information system called SAGE.

The technology stewards of the Manzanita community built SAGE with the help of students from a local university. The SAGE suite of information systems gained wide spread popularity due to its plant database that was crowd-sourced from local knowledgeable people. The SAGE Sustainable Polyculture Composer, a design application, especially drew the attention of newcomers to sustainable agriculture because it guided them through process of making an implementable design. However, it was the SAGE Forum that truly brought the communities together. Although the metropolitan area was vast, what could be grown and how to grow it was similar across the region, and the forum allowed people to learn from others that they otherwise did not have access to.

Today, the fiscally poor are collectively avoiding destitution. To obtain California's most precious resource without contributing to drought-related problems, many parts of the metropolitan area have implemented ad-hoc storm and greywater catchment and recycling systems that reduce the amount of water wasted and groundwater overdrawn or contaminated. To reduce water usage, farmers carefully select and interbreed agricultural plants for their lower water requirements. In the agricultural hubs, empty spaces have become locations for growing food or markets for distribution.

Not everybody is a sustainable agriculture farmer; there are still cars, trains, and airplanes that need mechanics, engineers, and pilots; there are still educators, crafters, and entertainers; there is still a food service industry; there is still law enforcement; there are still government and societal infrastructures to manage; even a tech industry remains. However, farming has become a common and well-respected livelihood, and many other livelihoods depended on local agriculture. In place of grocery stores, mega supermarkets, and fast food restaurants are permanent produce markets and prepared food stands that are integrated into neighborhood parks. The produce and prepared foods differ across the neighborhoods representing the ecological and ethnic diversity of the metropolitan area. Sustainable farmers do not all grow food. Some produce other important resources from agricultural products. Some citizens gather food waste, green waste (i.e., plant trimmings), and animal waste from farms or neighborhood parks and composted in biodigesters producing fertilizer for neighborhood crops and gas for cooking. Local, sustainable agriculture and food sovereignty has become part of the culture and at least in part supports the livelihood of most families in the area.

As the agricultural communities grew, knowledge became localized and embedded in the community, and the requirements for SAGE evolved. Now there are enough local experts that budding farmers learn directly from the old-timers and online social learning tools are no longer heavily used for local social learning. Now, the online social learning tools are mostly desired for collaborating with others in regions with a similar climate zone, like the Mediterranean. In the local context, the modern requirements for SAGE are less community-building driven, but more knowledge storage, sharing, and organization driven. With the support of technology stewards, the SAGE Plant Database continues to grow and evolve to meet the needs of the agricultural hubs, and a collection of visualization tools have been added to SAGE by enthusiastic users.

When first creating SAGE, the community had specific sustainability values for technology they used: it should be sustainably produced by, for example, using cradle to cradle resources; it should be effectively recycled to eliminate e-waste by, for example, modeling reconstitution as seen in nature; it should be simple and easy to understand; it should be open source, not proprietary, and should not be planned for obsolescence; it should support already obsolete hardware or software; and it should be modular so it is able to maximize utility by being multifunctional. Many of these requirements were not attainable at first, but over the years small portions of the tech industry began to provide a means to meet some of these requirements. For example, members of the sustainable agriculture community preferred modular computers because of the ability to change out components in cases of malfunction or need for specialized equipment, but modular computers only recently became available after component vendors joined computer companies in expanding into this innovative but risky market.

There are several reasons SAGE has been able to evolve, persist, and support the community for so many decades. One primary reason is because from the beginning it was a carefully planned design for this community, not a general audience. The community has been invested in the creation and maintenance of SAGE and values the services it provides them. Another important reason was because the community sustainably produced SAGE. Hosting SAGE online has allowed people with small storage space to access remote databases that contained more data than their devices could store. However, as standard web-protocols became more complex, developers had to update SAGE to new standards, and outdated technology could not be supported. However, because SAGE applications developed to have simple graphics and low computational needs, and they continue to run on some computing systems that are up to 10 years old. Porting SAGE to software for modular personal computers that communicated via peer-to-peer networks allowed the developers to focus on the needs of their community and not the tech industry standards. It also enabled the members in the sustainable agriculture community who lived “off grid” to use components of SAGE offline, ensuring that their data would not be lost due to circumstances that cause an interruption in their Internet connectivity.

CHAPTER 1:

Introduction

Like much of science in the last century (Descola and Pálsson 1996; Devall and Sessions 1985; Kates 2012; Latour 1993; Shapin 1982), this dissertation rejects the dualism of human and nature. Humans are inextricably a part of nature. And, as humans are a part of nature, so too is agriculture. Earth provides the constraints and opportunities for human life, and in return humans have shaped and modified Earth (Fedonkin 2009; Cleveland 2014). The relatively stable climate of the Holocene era (which began about twelve thousand years ago) enabled humans to begin engaging in agriculture, whereas in the previous era, the Pleistoscene, which had comparatively fast and extreme changes in climate with recurring growth and retreats of glaciers, humans could only engage in hunting and gathering (Cleveland 2014; Atahan et al. 2008).

For 2.5 million years, *Homo* physiological and sociocultural characteristics evolved for survival on Earth when their population and impact were relatively small (Cleveland 2014). However, "small" no longer characterizes the only remaining hominid species, *Homo sapiens,* in terms of either its population or its impact. Humans have induced significant changes to Earth's biogeochemistry by way of agriculture systems, and more recently, by way of our large consumption of fossil fuels and other natural resources (Jordan et al. 1990; Raven, Andrews, and Quigg 2005; Raven, Handley, and Andrews 2004).

Steffen et al. (2005) list agriculture as one of the human enterprises that thrust Earth into what some scientists propose should be called the Anthropocene epoch because of the ways humans have induced significant changes to Earth's biogeochemistry (Waters et al. 2016). In concert with other enterprises such as industry and international commerce, agriculture is "transforming Earth's land surface, altering its biogeochemical and hydrologic cycles, adding and deleting species, destroying and modifying ecosystems, and ultimately changing climate and biological diversity" (Steffen et al. 2005, 83).

Agriculture has alarming effects on ecosystem health and diversity (Horrigan, Lawrence, and Walker 2002; Bassil et al. 2007; Dich et al. 1997; Pimentel, Greiner, and Bashore 1998; Henry et al. 2012; Rabalais et al. 1996; Hallegraeff 2003; Barile 2004), and climate change (Bonan 2008; Vermeulen, Campbell, and Ingram 2012). Researchers and activists have criticized agriculture for falling short on addressing global issues of malnutrition (Traoré, Thompson, and Thomas 2012), and for perpetuating social inequality for farmers (Flora 2018; Graeub et al. 2016). These issues have propelled a decades long effort by researchers, activists, institutions, and governments into a more sustainable agriculture. However, creating and engaging in sustainable agriculture is challenging because it necessarily grapples with complexity from the natural ecosystems it must function within as well as the social ecologies that govern the morals, standards, and markets that shape the agrifood system.

The most notable effort towards sustainable agriculture among institutions, researchers, and activists is to reframe agriculture as an agroecosystem (FAO 2014, 2018a;

Mollison 1988; Altieri 2009; Gliessman 2015; Nesheim, Oria, and Yih 2015). An agroecosystem, sometimes called an agricultural ecosystem, is defined as a site or integrated region of agriculture production understood as an ecosystem (Gliessman 2015) and is characterized as " a hierarchy ascending from the level of the individual plant or animal all the way to national systems linked by international trade" (Conway and Barbier 1988).

This dissertation research supports the formation of local agroecosystems by grassroots sustainable agriculture activists. Specifically, I explore how grassroots sustainable agriculture communities of practice can aggregate distributed knowledge necessary for sustainable polyculture design. Sustainable polycultures (see Figure 1-1) are assemblages of complementary and mutually beneficial plant species, typically composed primarily of perennials, and are one kind of food- and other provision-producing construct in an agroecosystem. A community of practice is defined by Eckert (2006) as "a collection of people who engage on an ongoing basis in some common endeavor." Members of a community of practice know each other and use similar language, routines, and tools in context of forming and contributing to the community (Wenger 2000).

This dissertation engages with permaculture and agroecology – the philosophical and scientific underpinnings of the two participating grassroots sustainable agriculture communities. Permaculture is an ecological design philosophy and social movement that encourages people to provide for their own food, energy, shelter, and other material and non-material needs in a sustainable way (Mollison 1988). Permaculture utilizes services of

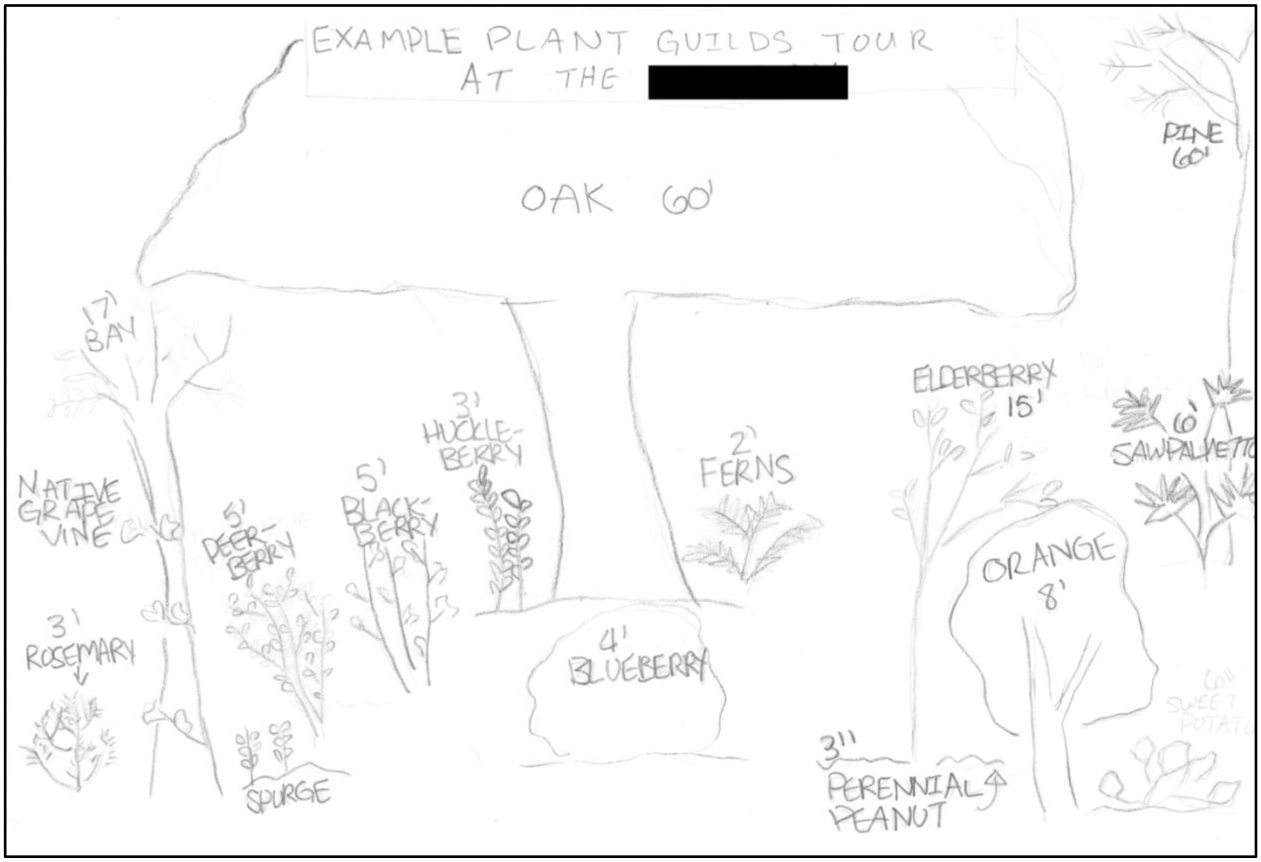


Figure 1-1 My depiction of a sustainable polyculture or "plant guild," as denominated by the participating communities.

the encompassing natural environment for people to generate their material and non-material needs. Permaculture also manipulates human-created outputs into services for their ecosystem. Agroecology is an agricultural practice and scientific field that applies ecology to agriculture (Lovell 2012). In building sustainable agroecosystems, agroecologists manipulate the flow of agricultural inputs and outputs in a way that is supported by and supports the encompassing ecosystem (Gliessman 2015; Cleveland 2014). In both permaculture and agroecology, the designed systems operate as a part of the ecosystem, both utilizing the resources and services provided by their ecosystems in an ethical, measured way, and also conscientiously accounting for the outputs.

The philosophical and scientific underpinnings of the participating communities frequently clashed with the values embedded in the information technologies (ITs) they adopted, including ones used to look for and manage plant information. Although ITs are well-suited to address the information complexities the participating communities encounter, many current IT initiatives, while well-meaning, fail to enact real-world change because they neglect deep engagement with their communities. The many facets of HCI research, such as action research, participatory research, activist research, and value-sensitive design, are well-suited to deeply engage with communities in the design of IT. This dissertation aims to provide an example of how to involve communities in the development of IT artifacts for sustainable agriculture and strengthen efforts around the globe that support sustainability via technological interventions.

1.1. Sustainable Polycultures

The grassroots sustainable agriculture communities that participated in this research featured sustainable polycultures as the foundational element of their agroecosystem designs. In terms of ecosystem organization, a sustainable polyculture is equivalent to a community of living organisms within an agroecosystem, meaning an assemblage of a various species living together in a particular place and interacting with each other. Sustainable polycultures have species in many vertical layers, optimizing the uses of space and services from other plants like shade or soil stabilization (see Figure 1-2). Other elements include those that support sustainable polycultures, such as a greywater system (see Figure 1-3). Greywater systems were used to water fruit trees, which are often require more water than other species, in sustainable polycultures.

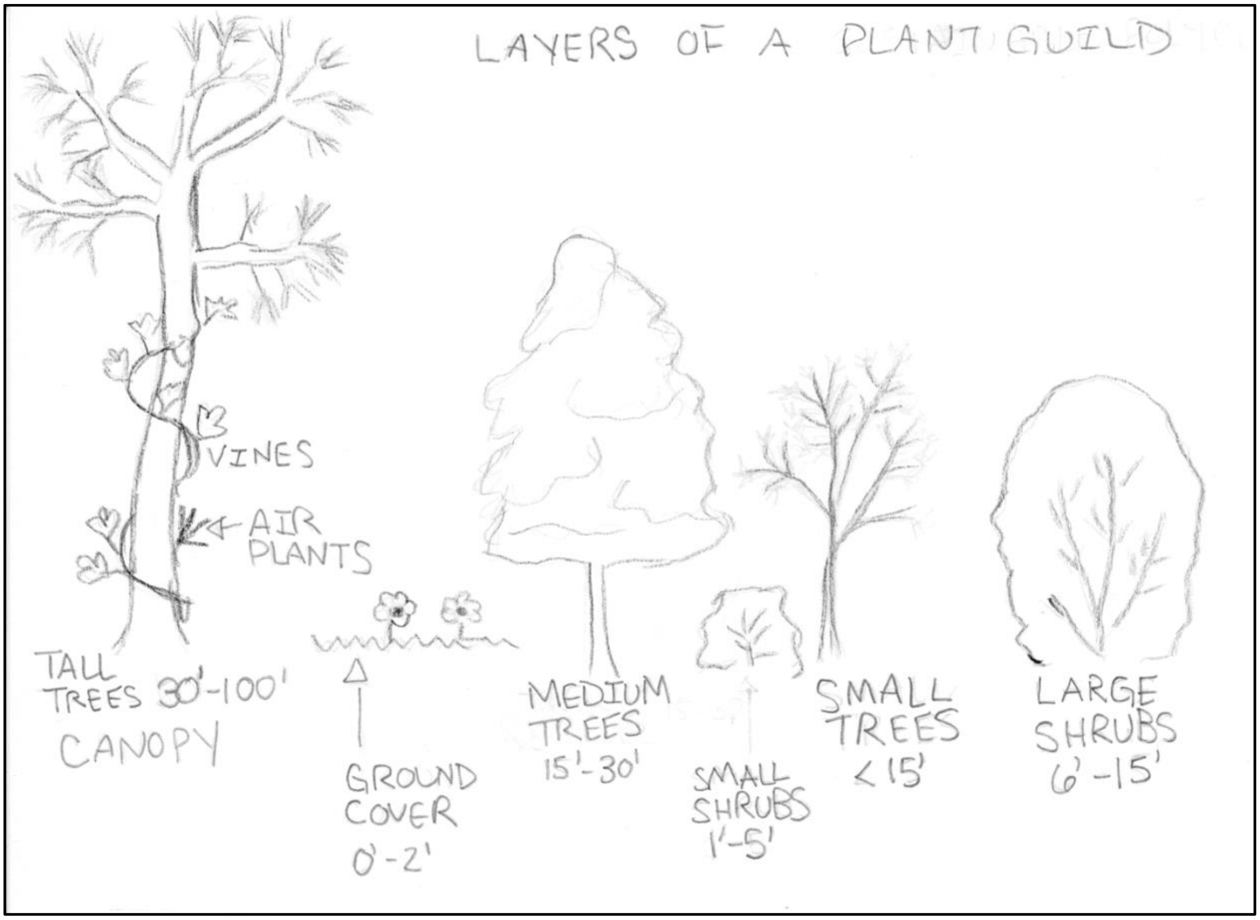


Figure 1-2 Vertical layers of a sustainable polyculture defined by a permaculture course instructor.

Participants in this research called sustainable polycultures “plant guilds”. This thesis introduces the term “sustainable polyculture” to replace the term “plant guild” because the scientific definition of guild does not match the concept of a polyculture. “Guild” scientifically describes “a group of species that exploit the same class of environmental resources in a similar way” (Simberloff and Dayan 1991). In other words, scientifically speaking members of “guilds” compete, but in permaculture they collaborate (Ferguson and Lovell 2013).

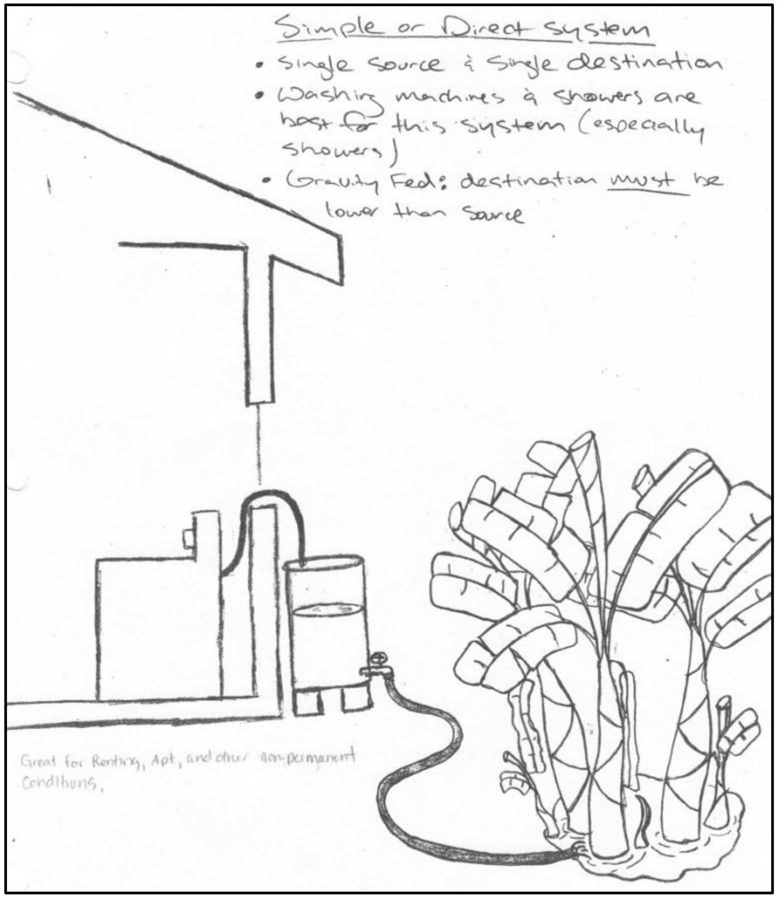


Figure 1-3 (Above): Simple greywater system example used as course material.

Figure 1-4 (Right): Herb spiral instructions used as course material.

How to Build a Spiral Herb Garden

By [redacted]

FIGURE 4. 30
HERB SPIRAL
Pattern applied. A modest 2 m diameter by 1 m high earth spiral accommodates all necessary culinary herbs close to the kitchen door and can be watered with one 2 m sprinkler—a considerable saving in space and water as the ramp and walls exceed 9 m of plant space

Step 1: Measure out the space to build an herb spiral, most are 5 feet square
Step 2: Remove grass or use the sheet mulching technique to decompose grass
Step 3: Add irrigation system if so desired
Step 4: Make the base structure of the spiral with rocks, wood, or found materials
Step 4: Fill the base structure with soil or compost
Step 5: Continue to build up spiral with structural materials and soil
Step 6: Plant herbs according to the microclimates
Step 7: Mulch
Step 8: Water in plants

** Photo from 4.30 Permaculture Designers Manual by Bill Mollison

Sustainable polycultures mimic natural ecosystems. Natural ecosystems are complex adaptive systems (i.e., "systems that change and reorganize their component parts to adapt themselves to the problems posed by their surroundings" (Holland 1992)) with high species and genetic diversities and complex trophic (i.e., nutrient-exchange) interactions. Sustainable polycultures require a similar degree of complexity to maintain the properties of natural ecosystems, like trophic interactions, that are beneficial for growing crops (Gliessman 2015).

Newcomers to the concept of sustainable polycultures often find their complexity and appeal difficult to understand without a visceral experience. The next section presents two examples of sustainable polycultures in different settings and ecosystems that have been used in a community or literature as a concept introduction.

1.1.1. Example Sustainable Polycultures

This section presents two examples of sustainable polycultures. The first is a representation of sustainable polycultures as observed and written by Brad Lancaster (2007, 273) in the Sonoran Desert. His depiction of a mesquite-based sustainable polyculture for agricultural production, which he refers to as a guild in the text, is based on his and a mentor's observations of plant-ecosystem relationships in the wild.

The second is an example scenario that attempts to demonstrate both the complexity and appeal of a sustainable polyculture in Central Florida. Alex Stringfellow, an early participant of this research, and I envisioned and authored this scenario to demonstrate a sustainable polyculture's complexity and nature in a backyard setting – a setting that was common in the grassroots communities.

Sustainable Polyculture in the Sonoran Desert

The velvet mesquite tree (*Prosopis velutina*) is the central pillar of many Sonoran desert guilds. Flowers cover the tree in spring and summer attracting over 60 native pollinators (Bowers 1993). Sweet and nutritious seedpods then form. Javelina, coyote, birds, and other wildlife consume the pods and leave manure behind. This improves the soil, as does decomposition of remaining seedpods, accumulation of fallen leaves, and the nitrogen-fixing action of beneficial bacteria living within root nodules on the leguminous tree.

This self-fertilizing island provides excellent wildlife habitat and a farmers' market of food plants. Beneath the mesquite, desert hackberry (*Celtis pallida*), greythorn (*Ziziphus obtusifolia*), and wolfberry (*Lycium* spp.) form an intertwining canopy of thorny foliage, with edible berries that birds love. A young saguaro (*Carnegiea gigantea*), and even a chiltepine (*Capsium annuum* var. *aviculare*), may grow underneath the mesquite, gaining protection from excessive sun and cold. The young saguaro will harden to the elements and eventually rise high above the mesquite, its flowers attracting insects, bats, and birds whose pollination services will help produce heavenly fruits. The chiltepine is a wild chile with a devilishly hot taste. The birds feast on this fruit, along with that of the wolfberry, hackberry, and greythorn, and feed the soil with their phosphate-rich droppings. Digested seed from the fruit of the guild is dispersed as birds fly off and deposit manure in other areas. In fact, some seeds, such as the wild chile, need to pass through a bird's gut to enhance their germination. As naturalist and chile-addict Gary Paul Nabhan notes, chiltepines are so keenly associated with birds that many of the common names refer to this relationship: bird pepper, pico pajaro, pajaro pequeno, and so on (Nabhan 1986).

The plants and animals of this guild act as a living community, sustaining and improving itself through many beneficial relationships among its varied life forms. Wildlife is the mobile planter, expanding the community's territory. Vegetation works the soil, its roots breaking up and aerating the earth to allow more moisture infiltration when it rains. Plant leaves drop and collect, creating organic mulch, which stabilizes, protects, and ultimately becomes the soil. This mulch also creates conditions in which beneficial mycelium or fungi can thrive and expand the guild within the soil. The fungi sends out branching networks of root like growth, further permeating and stabilizing the soil as it helps break down the mulch. Some of this mycelium also attaches itself to the roots of the plants in effect increasing the plants' root network. The fungi then help provide the plants with essential nutrients and additional moisture, while the plants provide the fungi with sugars (Stamets 2005).

- Brad Lancaster (2007, 273)

Although it may be easy to picture yourself in these example sustainable polycultures, designing them and ones like them into a reality is a difficult challenge. The next section describes sustainable polyculture design in the context of grassroots sustainable agriculture communities.

Sustainable Polyculture in Suburban Central Florida
Picture yourself stepping out into a quiet backyard; your property is fenced in with an assortment of sugarcane and bamboo, protecting your privacy, and your other plants from wind. This same bamboo plant was used to build the bench you just sat down on. You gently stir your morning tea with a sweet cutting of sugarcane, yet another function of your privacy fence. A brigade of bees and butterflies hover busily around your native goldenrod, gaillardia, coreopsis, milkweed, and sunflower. Where you would normally have grass, the native and hardy gopher apple gladly covers the ground; you even occasionally see a gopher tortoise creep into your yard and lazily munch on his favorite snack. A large persimmon tree provides seasonal shade for your bench as well as a nice little treat for you and the local wildlife. A passionflower entangles the persimmon tree, while its flower bobs happily around in your tea. You begin to search for salad ingredients, your lunch, occasionally picking a few blackberries and sparkleberries; they taste quite like a blueberry, but half the maintenance. You pull a couple of leaves off the French sorrel, the *Moringa*, and fennel. To top it off, you snag an avocado and some rosemary.

- Juliet Norton and Alex Stringfellow, 2012

1.1.2. Sustainable Polyculture Design

Creating an implementable sustainable polyculture design requires designers to identify one or more key species to serve as the underpinning of the sustainable polyculture. The key species (e.g., an avocado tree) has to be suitable for the environment and typically has some significant human value (e.g., food). The designer then performs a functional analysis to identify the key species' intrinsic characteristics, needs, and products or services. A species' needs are its inputs, including sunlight, water, and nutrients. A species' products or services are its outputs, such as fruit, shade, mulch, protection from wind, and pest-deterring oils. These attributes are used to design working relationships between each element to create a functional ecosystem.

The designer uses the attributes defined in a functional analysis to design working relationships between each element in the sustainable polyculture. Support species are selected based on their ability to produce products or services that the key species needs. Many support species are identified to fulfill each need of the key species to ensure that its needs are resilient to failure of a single support species. Additionally, the designer performs functional analyses on the support species and determines support species for those already selected support species to ensure their needs are met and resilient to failure. It is through the recursive incorporation of support species that a sustainable polyculture mimics an ecosystem.

This design process, the cyclical functional analyses of species and arrangement of working relationships, is tedious because it takes a long time and is detail-oriented. A designer must determine how many iterations of functional analyses on support species are needed to create a robust-enough sustainable polyculture. This requires a designer to determine which ecosystem properties are essential to adopt into the design of a sustainable polyculture and which ones can or should be foregone to maintain a healthy crop and productive yield, adhere to monetary constraints, and maintain a human-manageable complexity.

Sustainable polycultures are implemented in many ways beyond that depicted in Figure 1-1. The herb spiral is perhaps the most common introductory implementation, of the sustainable polyculture concept because it is simple in design, quick and easy to implement, and inexpensive to build and maintain (see Figure 1-4). Herb spirals are polycultures of herbaceous shrubs and groundcover arranged in a spiral with deceasing elevation as the spiral progresses outward. In concept, an herb spiral supports a variety of growing environments for herbs. For example, herbs lower down in the soil will have moist soil for a longer duration than herbs higher in the spiral, and herbs on the north

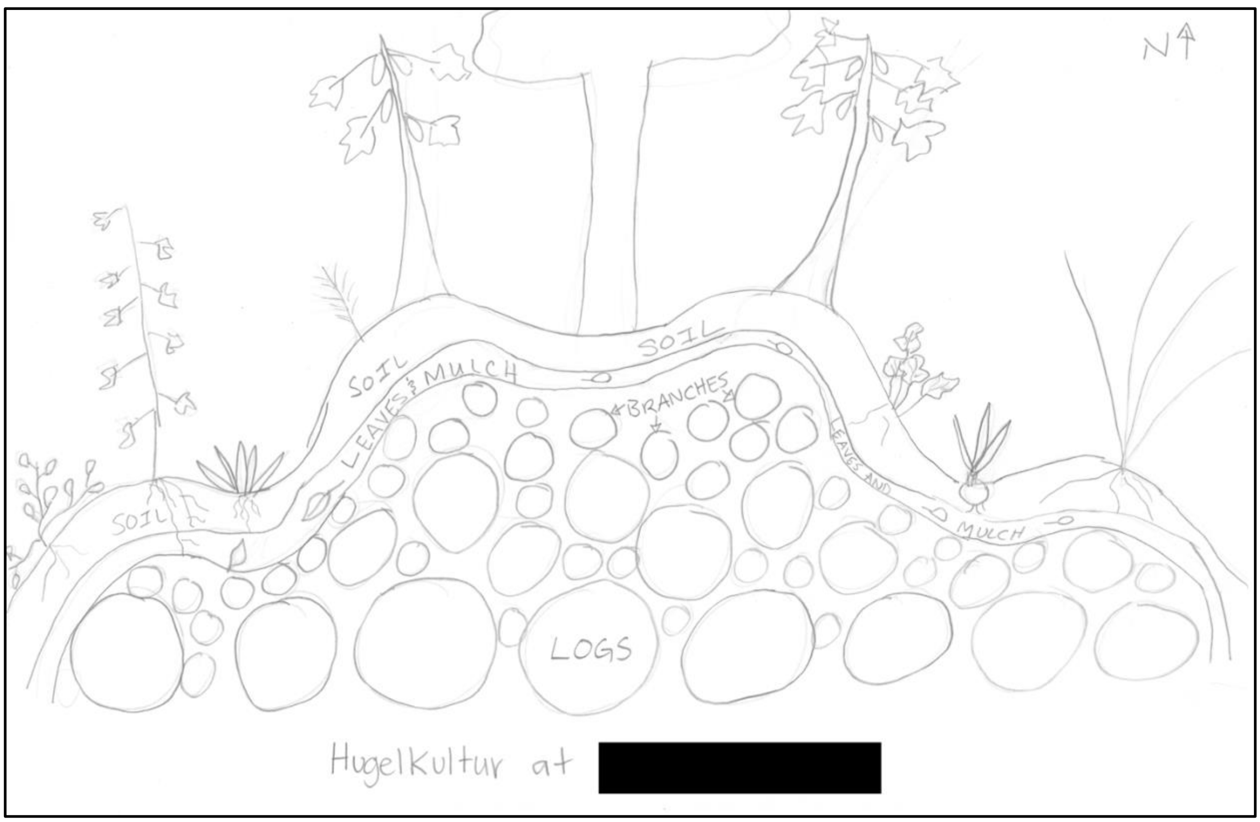


Figure 1-5 My depiction of a hügelkultur at a community education center.

side of the spiral will receive shade from herbs on the south side. The designer chooses plants based on their products such as, food or fragrance, and services, such as pollination or pest deterrence. The designer then places plants based on factors such as water needs, soil drainage tolerance, and pollinator attracting and pest deterring species. Many other factors considered in a full sustainable polyculture design, such as nutrient cycling, are ignored by the expectation that the herb spiral will require external inputs and maintenance. For example, the herb spiral may require seasonal soil amendments, but ideally those fertilizers are natural and produced on-site (e.g., worm castings or compost).

Another way sustainable polycultures are commonly implemented is as a hügelkultur. Hügelkultur is a German word that translates into English as "hill culture." Hugelkultures are popular because they provide nutrient rich, aerated soil for decades. In a hügelkultur, branches, leaves, and other kinds of biomass form a large mound and are covered with soil, creating what is essentially a raised bed (see Figure 1-5). The sustainable polyculture grows on and beside the mound to take advantage of the nutrient-rich, moisture-retaining, well-aerated soil.

1.2. Summary of Research

This research explores if community-specific information technologies can strengthen and support activists' work to address agriculture-induced and agriculture-affected global change. My **informatics research objective** is to uncover and address challenges that prevent the integration of information technology into grassroots sustainable agriculture information ecologies. My **activist objective** is to work with grassroots sustainable agriculture communities to address the lack of region-specific plant data needed for sustainable polyculture design. These objectives are labeled as "informatics research" and "activist" to indicate the dominant intended contribution. However, both objectives yielded meaningful contributions to both the field of informatics and sustainable agriculture activism.

The remainder of the dissertation is presented in five chapters. Chapter 2 introduces the theoretical framing, HCI and agriculture contexts.

Chapter 3 introduces the communities that participated in this research, the research methodologies, and data analysis techniques.

Chapter 4 demonstrates how newcomers to the communities faced a number of information challenges that hindered legitimate peripheral participation in agroecological design and practices. Most relevant to the remainder of this research, though, are those challenges regarding access to and organization of information needed for sustainable polyculture design. This chapter also presents the communities' emergent resistance, technology values, and long-term values and goals and how they could manifest in the information systems they use.

Chapter 5 introduces the technology developed to address the information challenges surrounding the design and development of sustainable polycultures. The SAGE (**S**oftware for **Ag**ricultural **E**cosystems) Plant Database was designed to provide newcomers and existing practitioners with the plant information necessary to thoroughly engage with sustainable polyculture design. This chapter presents the requirements, design, and implementation of the SAGE Plant Database. I argue this plant database differs from others because it is designed for a specific community, because it supports agroecosystem design, because it can serve as a foundational tool for other software that supports agroecosystem design, and because it can be adapted and updated for other communities with similar values and engaging in similar activities. At the end of this chapter, I engage in a grounded comparison of the SAGE Plant Database to other plant databases and the information ecology contexts they exist to evaluate the actuality of these statements.

I end the dissertation, Chapter 6, with a summary of contributions, a critical discussion about the limitations of this research, and opportunities for future work.

CHAPTER 2:

Background

This dissertation intersects three primary domains: sustainable agriculture, human computer interaction (HCI), and sustainability activism. In this chapter I present the information necessary for the reader to engage with the topics discussed in the remainder of the dissertation. I provide the theoretical framing for this research, related work in HCI, and a review of the agricultural context. The agricultural context section provides those readers less familiar with the subject with additional background information required to understand the remainder of the dissertation.

2.1. Theoretical Framing

2.1.1. Information Ecologies

This research engages with two information ecologies – a suburban farm and community education hub, and a center for sustainability and ecological agriculture (see Figure 2-1). An information ecology, as defined by anthropologists Bonnie Nardi and Vicki O'Day, is a "complex system of parts and relationships" with a focal point on human activities that are served by technology (Nardi and O'Day 2000, 50). An information ecology is location specific, meaning it has a local context that makes up the parts and influence the relationships in the system. The reason these complex systems are called ecologies is because they "exhibit diversity and experience a continual evolution," in which

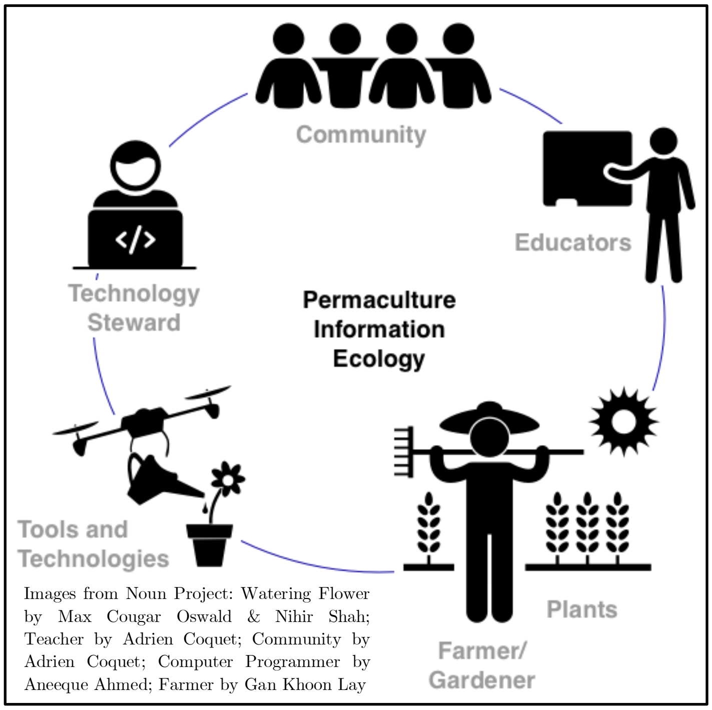


Figure 2-1: Depiction of participating communities as an information ecology.

different parts "coevolve, changing together according to the relationships in the system" (Nardi and O'Day 2000, 50–51).

Nardi and O'Day described issues that occur when new technologies are introduced into information ecologies, three of which are relevant to this dissertation. First, new technologies are added to an information ecology with the intent to operate in absence of an essential keystone species, which is often a person(s) that is "necessary to the survival of the ecology" and whose skill is needed to support the effective use of the new technology (Nardi and O'Day 2000, 51, 53). Second, the designers and engineers decide which information is relevant and how it should be displayed and engaged with, thus determining what values and social agendas to embed in the technology, even if unwittingly. Through "reverse adaptation" the users of these technologies adjust their goals "to match the character of the available means" (Winner 1977, 229). Thirdly, all outcomes of introducing a new technology into an information ecology cannot be predicted, and often the possibility of unknown or negative side effects are ignored by designers, engineers, and users. Unintended consequences of a new technology may be detrimental to relationships, parts, or all of an information ecology (Nardi and O'Day 2000, 41; Winner 1977).

Nardi and O'Day suggest three ways in which designers and users should be involved when successfully integrating a new technology and evolving an information ecology: working from core values; pay attention, particularly to the spaces; and ask strategic open-ended questions. *Core values* "are the center of gravity of a healthy information ecology" (Nardi and O'Day 2000, 67). Core values should drive the need for and presence of technology and be reflected within the technology. In addition, using the technology should help one achieve those values. *Paying attention* to the merit of a practice or technology is a critical component for properly matching technologies with working practices. Technology designers must take special care to avoid assuming "the way something is now is the way it has always been or must be" and "the way something is now has no particular motivation or rationale behind it" (Nardi and O'Day 2000, 68–69). Determining the merits of practices and technologies requires looking beyond the obvious, particularly the technologies, into "the spaces" between (e.g., relationships, activities) where the "critical and often invisible things happen" in effort to understand why things are the way they are (Nardi and O'Day 2000, 66–69). Asking *strategic questions* helps identify core values, merits of practices and technologies, and critical happenings in "the spaces." Questions that provoke thought experiments and are open-ended without a fixed set of possibilities help express motivations, objectives and values (Nardi and O'Day 2000, 70–71). Because local knowledge is distributed through an information ecology, strategic questions should be formulated for and responded by many community members (Nardi and O'Day 2000, 74).

2.1.2. Activist Research

Activist research is a form of collaborative research in partnership with powerless communities in their process of pursuing some form of social change that equalizes the status quo (Cancian 1993). Activist research requires dialogue and collective work with activists prior to finalizing research questions and research objectives (Hale 2001). Activist research also necessitates the efforts on building trust with the activist communities (Martínez 2008). Drawing on his and other activist researchers' experience, anthropologist João H. Costa Vargas (2008) emphasized that researchers should act as activists and actively participate in the activist communities.

Human Computer Interaction (HCI) researchers suggest that those exploring sustainability should build partnerships with sustainability activists (Goodman 2009; Dourish 2010; Silberman et al. 2014; Håkansson and Sengers 2013; Nardi 2013; Tomlinson et al. 2013; Prost, Schrammel, and Tscheligi 2014). Busse et al. highlighted varying views of the leading HCI conference's (CHI) "role in supporting or enabling activist causes," from "the positive interaction of science, design and activism" to "a dispassionate objective role – both in research and teaching" (Busse et al. 2013). Knowles et al. (2014) argued that the Sustainable-HCI (SHCI) community cannot avoid being political if they are to affect meaningful change – presenting people with facts alone is not effective because people can shut out information that makes them uncomfortable. SHCI researchers, they argued, need to construct their identity as activists. However, Knowles and Eriksson (Knowles and Eriksson 2015, under “Interlude 2: A reluctant academic deviant”) note the difficulty of being activists and maintaining academic integrity – “how does one avoid the ‘hot-head’ label often given to activists and build a career as a respected academic?”

Engaging in research as an activist challenges the perception that objective research is required for scholarly rigor. Activist research is at its core anthropological, and anthropological inquiries are sometimes considered subjective and lacking in scholarly rigor because they are emotionally based, non-replicable, and deduced by a researcher who may not have appropriate domain knowledge of the subject matter (Leeds 1974). However, the philosopher Amartya Sen points out that, for all scientific endeavors, all observations are position-dependent (Sen 1993), and that position-dependent observations provide the primary information used to create “position-independent generalizations“ (Sen 1992). In contrast to moving towards objectivity, as described by Sen, Hale argues that activist research leads to “a deeper and more thorough empirical knowledge of the problem at hand, as well as a theoretical understanding that otherwise would be difficult to achieve” (Hale 2006).

Links between activist and academic goals are historically tenuous. Activist initiatives may fail in achieving long term change but succeed in spreading awareness or otherwise inching towards lasting change. Cancian (1993) demonstrated how such “failures” or unmeasurable success does not align with the academic expectations to produce successful, informative, and measurable experiments. Successful activists have had strained relationships with academia and successful academics have had difficulty developing strong ties with activist communities (Cancian 1993). Hale (2008) subtly characterized this phenomenon by defining activist research as an alternative form of research that "contributes to social good" and only "modestly advances the frontiers of knowledge." However, Stoecker (1999) argued that as researchers become activists and other forms of participatory research, such as action research, become more prevalent, activist and research goals will continue to improve in commonality.

2.1.3. Action Research

In this dissertation, I engage in *action research.* Action research is a form of collaborative research in partnership with the community of focus (Lewin 1946; Adelman 1993). Action research is the process of conducting research *with* community members to *improve* a situation. Action research is not an explicit procedure, but instead is an iterative and open-ended process of forming and addressing problems through observation and practice (McTaggart 1996). Change brought about by action research is introduced iteratively. A problem is formulated, a solution (e.g., policy, information system, etc.) is designed and deployed, its effects (i.e., change) are observed, and then the researcher reflects and then redefines the problem to start the cycle again. A researcher can use qualitative and quantitative methods in action research but should not distance herself from the context for “objectivity” reasons. Necessarily, the values of the researcher and the community drive the action research methods used.

Action research is well suited for addressing complex and intractable problems. Action research is depicted as a spiral to represent its effort to iteratively arrive at “a better solution” to a problem rather than end at “the solution.” Instead of finding solutions that are generalizable, action research produces solutions that are trustworthy (i.e., credible, transferable, dependable, and confirmable) (Lincoln and Guba 1985; Stringer 2013).

HCI researcher Gillian Hayes has argued the relevance of action research methods in HCI and computing research that aims to have substantial societal benefits (Hayes 2011). Working with community partners, engaging in fieldwork, and designing and developing solutions iteratively are action research methods familiar to HCI. However, the action research approach to these methods is unique especially regarding the familiarity of the researcher with the community and the commanding role the community has in the research. Hayes compares the iterative nature of User-Centered Design to action research but contrasts its tendency to arrive at “the solution.”

2.2. Related Work in HCI

Bødker (2006, 2015), Sengers, Boehner, and Knouf (2009), and Harrison, Tatar, and Sengers (2007) mapped HCI’s trajectory in “waves” and “paradigms,” noting the evolution from human factors and classical cognitivism to phenomenologically-situated interaction, from research that focused on individual-user contexts to that focused on groups, and from work contexts to broader cultural contexts. This research works with participating communities in a number of contexts, from individual work and learning to community activism. My research is also phenomenologically situated, meaning it is focused on making meaning based on human experience represented through multiple perspectives and the relationships among those perspectives (Harrison, Tatar, and Sengers 2007).

My work supports two sustainable agricultural activist communities specifically but aims to support sustainable agricultural activist communities more broadly. Harrison, Tatar, and Sengers (2007) explain that meaning is derived from information and that meaning is dependent on viewpoints, interactions, histories, and local resources to make sense of that information. Because of the potential variance in meanings, the information systems I designed and built may only support the specific sustainable agriculture activist groups that participated in this research. However, I designed these systems to be adopted and adapted by any permaculture community and other groups that derive similar meaning from environmental and social information.

The remainder of this section reviews the related work in four HCI subfields that this work draws upon: values in the design of information systems, sustainable informatics, collapse and adaptation informatics, and food and agriculture in HCI.

2.2.1. Values in the Design of Information Systems

How human values take shape in and are shaped by IT is a widely discussed topic in HCI (Borning and Muller 2012; Erickson et al. 2012; Friedman, Kahn, and Borning 2006; Iversen, Halskov, and Leong 2012; Koepfler et al. 2014; Le Dantec, Poole, and Wyche 2009; Nardi and O'Day 2000; L. P. Nathan 2008; Yoo et al. 2013). The set of values of particular concern to the HCI community is expansive, including privacy (Warshaw et al. 2015; Gou, Zhou, and Yang 2014), trust and accountability (Friedman et al. 1999), safety and security (Denning et al. 2010; Friedman et al. 2002; Woelfer et al. 2011), sustainability (Blevis 2007; Hanks et al. 2008; Mankoff et al. 2007; Penzenstadler et al. 2014; Raturi et al. 2017) and self-enhancement (Knowles 2013).

My work utilizes the concepts in value sensitive design (VSD) as developed by Friedman, Kahn, and Borning (2006) for incorporating values into the design of information systems. VSD seeks to influence the design of technology, based on values of moral significance, throughout the design process. VSD involves identifying the harms and benefits of each stakeholder group of a designed technology, mapping those harms and benefits to moral values, and integrating those value considerations into the design. My research investigated the harms, benefits, and moral values of the stakeholders, and incorporated those values into the design of the SAGE Plant Database accordingly.

2.2.2. Sustainable-HCI

Sustainable-HCI (S-HCI) is a subfield of HCI that is concerned in some way with sustainability. DiSalvo, Sengers, and Brynjarsdóttir (2010) first "mapped the landscape" of S-HCI and Knowles et al. (2013) followed up with a different systematic mapping method in 2013. In context of the first mapping (DiSalvo, Sengers, and Brynjarsdóttir 2010), the first portion of this research falls under "formative user studies" genre, whereas the second portion, building the system, falls into "designing for sustainability" as described by Knowles et al. (2013).

Formative user studies within S-HCI that are relevant to this research include those engaging with people who lead alternative sustainability life styles (Blevis and Blevis 2018; Blevis and Morse 2009; Håkansson and Sengers 2013; L. Nathan 2009; Norton, Stringfellow, and LaViola 2012; Tsaasan and Nardi 2018), and research engaging with people who grow food (Ardianto 2014; Bødker, Korsgaard, and Saad-Sulonen 2016; Leshed, Håkansson, and Kaye 2014; Odom 2010; Wang et al. 2015).

Research into designing for sustainability that is relevant to this research includes that which involves technologies that support the work of farmers and gardeners (Hargreaves and McCown 2008; Sethu-Jones, Rogers, and Marquardt 2017; Heitlinger, Bryan-Kinns, and Comber 2018), citizen science for gathering data necessary for sustainability initiatives (Wibowo et al. 2017; Paulos et al. 2008), using a crowd for participation in sustainable behavior (Massung et al. 2013; Sakamoto and Nakajima 2013), and sustainable interaction design (Blevis 2007; Blevis et al. 2017; Egan and Benyon 2017; Preist, Schien, and Blevis 2016).

2.2.3. Beyond Sustainability in HCI

Collapse informatics, adaptation informatics, and Computing within Limits are complementary fields that explore the shortfalls of the mitigation approach of sustainable-HCI. Collapse informatics is the study, design, and development of technologies in the “abundant” present for use in a future characterized by scarcity (Tomlinson et al. 2013). Collapse informatics is motivated by the concept of societal collapse, which Tainter (1988) famously defined as a rapid decrease in established societal complexity. Adaptation informatics is the study, design, and development of technology for use in a future characterized by global change (Tomlinson et al. 2012). Computing within limits, is a relatively new area of research that explores the limits of computing in context of ecology, materiality, and energy (Nardi et al. 2018).

The research within this domain most relevant to this dissertation is the rapid obsolescence of technology (Jang et al. 2017; Tomlinson et al. 2015; Remy and Huang 2015), communities adapting to resource scarcity (Patterson 2015; Pargman and Wallsten 2017; Gui and Nardi 2015b), and preparing modern systems and infrastructures for long-term use (Silberman 2015b; Friedman and Nathan 2010).

2.2.4. Food and Agriculture in HCI

Food is a widely researched topic in HCI that has emerged as a subdiscipline called food-CHI, in reference to the CHI conference and publication community. Food-CHI has some overlap with Sustainable-HCI, such as in the context of those exploring and designing sustainable food systems (Norton et al. 2017; Kuznetsov, Santana, and Long 2016; Kuznetsov et al. 2016; Ng et al. 2015; Raturi et al. 2017; Heitlinger, Bryan-Kinns, and Jefferies 2014). However, much of food-CHI researches the intersection of HCI and other food topics such as cooking, nutrition, food waste, and food deserts (Choi, Foth, and Hearn 2014). The food-centered research in HCI most relevant to this dissertation is the research on supporting people who grow food (Geller 2016; Hussain 2016; Leshed, Håkansson, and Kaye 2014; Odom 2010; Raghavan et al. 2016; Suen et al. 2014).

2.3. Agriculture Context

2.3.1. Agriculture in the Age of the Anthropocene

This section introduces the origins and practices of modern agriculture, and the reasons why agriculture needs to be more sustainable. In the mid-twentieth century, industrial and developing societies brought modern industrial agriculture to bear on the problem of feeding a growing population. Modern industrial plant agriculture typically consists of monocultures heavily dependent on water, synthetic fertilizers and chemical insecticides. The predominant plant crops world-wide are “modern” or “high yield” varieties of cereals, pulses, and tubers for food, feed, fiber, and fuel (FAO 2018e).

Scientists and institutions characterized the success of modern varieties (MVs) as a "Green Revolution" (Evenson and Gollin 2003; Conway 1998). Gollin et al. (2018, 2) explain that the Green Revolution "emerged from philanthropic efforts ... to address the challenges of rural poverty and agrarian unrest in the late 1950's and early 1960's, and it involved a concerted effort to apply scientific understandings of genetics to the development of improved crop varieties that were suited to the growing conditions of the developing world." Based on longitudinal international research and impact models from 1960-2000 (International Food Policy Institute 2015), Evenson and Gollin (2003) suggested that the Green Revolution considerably raised the health status of preschool children and lowered the infant and child mortality rates in developing nations. In his retrospective review of the Green Revolution, Pingali (2012, 1230) demonstrates that Green Revolution "contributed to widespread poverty reduction, averted hunger for millions of people, and avoided the conversion of thousands of hectares of land into agricultural cultivation."

However, these successes were accompanied by unintended negative consequences (Shiva 2016; Dawson, Martin, and Sikor 2016). In the post-Green Revolution, Pingali (2012) shows, food insecurity persists, nutrition is lagging, and environmental impacts were mixed. Pingali characterizes these costs as unintended negative consequences, not because the technology was bad, but because of the policies that encouraged rapid implementation these technologies. Policies led to interregional food security disparities in South Asia (Fan and Hazell 2001) and South America (Altieri and Toledo 2011), a lack of support for women in agricultural technology transfer (McIntyre et al. 2009), the abandonment of micro-nutrient rich traditional crops for incentivized staple crops (Cagauan 1995; Welch and Graham 2000), and the over-use of inputs such as fertilizers, pesticides, and irrigation water (Pingali 2012; Welch and Graham 2000).

Food insecurity, as defined by the New Oxford American Dictionary (*New Oxford American Dictionary* 2010), is the state of being without reliable access to sufficient quantity of affordable, nutritious food. Food insecurity is an ongoing matter with an increase in world undernutrition (i.e., hunger) since 2015 to 821 million people, and a long-continued global increase in micronutrient deficiency among the non-hungry that leads to obesity (FAO 2018b). Regarding addressing food insecurity in the long-term, the United Nations Food and Agriculture Organization (FAO 2009, 17) argues that "global resources are sufficient," estimating enough food can be produced for the forecasted peak population of 9.1 billion people. Instead, the FAO argues that food security is limited by economic and institutional frameworks in the distribution of the available food stores. The FAO argues that food security is also limited by local resource constraints and the overuse of resources until a tipping point is reached and the society becomes impoverished.

Obesity and other effects from improper nourishment are most prevalent in North America (FAO 2018b). In 2006, the USDA reported that 7.4 million acres of additional cropland would need to be harvested for Americans to eat the nationally recommended diet because the domestic food system at the time did not produce enough fruit, vegetables, or dairy (Buzby, Wells, and Vocke 2006). Furthermore, the they indicated that the agricultural industry over-produced grains, but American's were still receiving too few whole grains because much of it was being consumed as refined-grains. The report suggested that grain production could decrease by 5.4 million acres and, with replacing refined grains with whole grains, still have enough grain to satisfy the recommended US Diet. More recently, the USDA shows that MV of corn, wheat, rice, and soy are still over consumed and fresh fruits and vegetables are under-consumed (USDA ERS 2017a) and have been implicated in the obesity epidemic (Siegel et al. 2016; Fields 2004). Scientists and journalists have long implicated governmental subsidies and other food-aid programs in the cause of obesity and improper nourishment (Siegel et al. 2016; Pollan 2016), but others have refuted this point (Alston, Sumner, and Vosti 2008).

Obesity linked to an unbalanced diet is also growing globally. In many developing nations, displacing small, multi-crop, and non-staple farms with large monoculture staple farms diversifies food availability and changes local diet (Alexandratos and Bruinsma 2012). For many people, the change in diet has been reduction in diet diversity, which perpetuates micronutrient deficiency (Traoré, Thompson, and Thomas 2012). People who experience such a change in their food system undergo a "nutrition transition" to refined foods high in fat, sugar, and salt which lead to obesity (FAO 2018b), disproportionality affecting financially insecure people because traditional varietals now have a higher market price (Traoré, Thompson, and Thomas 2012). Other nations that are experiencing large socio-economic changes suffer from the "double burden of malnutrition" (FAO 2018b, 27), in which financially insecure people are undernourished and financially secure people are obese. In this case, those who are obese now have money and access to food, but cannot productively process that food because they are metabolically adapted to hunger from their youth when they were undernourishment (FAO 2018b).

Modern industrial agriculture also fosters socioeconomic inequality among farmers across the world (Flora 2018; Graeub et al. 2016; Lobao and Stofferahn 2008). Policies across the world encouraged farmers to transition into growing MV crops for their high productivity (Tripp 1996). Globally, MV seeds and infrastructure, such as irrigation and tractors, are respectively expensive to buy and operate while the products have a comparatively low market value (Rosset 2006). The upfront cost is too great for small farms during the transition from subsistence farming; they often go into debt and then lose farms because they are not able to turn a large enough profit (Rosset 2006). In the US, instead of institutions that foster personalized connections between farmers and consumers that support medium and small diversified farms, what crops are grown and how they are grown is largely dictated by governmental subsidies, loan structures, and insurance (Yu and Sumner 2018; Roberts, O'Donoghue, and Key 2007; Young and Westcott 2000). These policies shape operating costs in such a way that helps only large farms succeed in turning a profit (OECD 2016).

In the United States, small and medium sized farms are shrinking in number, and large farms are growing in space, production, and profits (USDA ERS 2014). The number of farms has reduced from 7 million in 1935 to 2 million in 2016 (USDA ERS 2017a), with 2.2% of farms controlling over a third of all crop land (Ferdman 2014). In 2015, most farms operated above the US-median house hold income of $56,516, but many supplemented their household income with income from off-farm sources (USDA ERS 2017a, 2017b). For the farms accruing less than $10,000 in sales, which accounts for 48% of all farms, farm production had a median negative effect on household income, meaning the farms operated at a financial loss (USDA ERS 2017a, 2017b). In contrast, farms that made over $1,000,000 in sales had a median household income of over $300,000 from farming alone. Developing nations transitioning to industrial agriculture are also experiencing trends of increasing economic disparity among farmers (National Research Council (U.S.) 2010).

Researchers and activists often characterize modern industrial agriculture as unsustainable because of its contributions to global climate change and other forms of environmental degradation. Clearing forests for crop land leads to changes in the hydrological cycle and reduction in carbon sequestration (Bonan 2008). Modern industrial agriculture creates up to 25% of global anthropogenic greenhouse gases from pre-production processes (e.g., manufacturing fertilizers and pesticides), production (e.g., soil tillage and biomass burning) direct and indirect emissions from agriculture), and post-production processes (e.g., waste disposal, storage, and transport) (Vermeulen, Campbell, and Ingram 2012).

Scholars also implicate modern industrial agriculture in reducing ecosystem health and diversity. Applied pesticides and fertilizers contaminate the water, soil, and air, poisoning humans, animals, and microorganisms (Horrigan, Lawrence, and Walker 2002).

Excess nitrogen in soil reduces plant diversity and reproductive success (Horrigan, Lawrence, and Walker 2002; Vitousek et al. 1997). Certain pesticides have been proven to cause cancers in animals and linked to cancer cases and other health concerns in humans (Bassil et al. 2007; Dich et al. 1997). Particular pesticides have been linked to a long term decline in bird and beneficial insect populations (Pimentel, Greiner, and Bashore 1998), including honey bees (Henry et al. 2012). Agricultural run-off in the Mississippi River created ecological "dead zones" in the Gulf of Mexico (Rabalais et al. 1996), contaminates large bodies of fresh water with blue-green algae blooms like the 2018 Lake Okeechobee algae bloom (Gomez 2018), and may exasperate naturally occurring red tides (Hallegraeff 2003, 18; Barile 2004) like the 2018 Florida red tide (Associated Press 2018).

Modern industrial agriculture also exhausts the natural resources it needs to function. It depletes accessible groundwater resources, which takes thousands of year to recharge, for irrigation (Gleick and Palaniappan 2010) and degrades soil, which is also a precious and difficult to rebuild resource, through poor farming practices such as seasonal tillage (Lal 2004). These global changes strain the efficacy of all forms of food and agricultural systems, from small farm families to large industrial farming organizations. The agriculture industry suffers from ongoing significant declines in crop and livestock production from climate change induced stresses; societies are struggling with availability of food and water during intensifying droughts; humans are facing food, water and vector borne disease (U.S. Global Change Research Program 2014).

2.3.2. Sustainable Agriculture

Neither activists nor researchers share a canon definition or vision of a "sustainable" food and agriculture system, because these are formed by varying views and political climates (Aerni 2009). Agroecologist David Cleveland argues that the term "has been used to mean everything from giant, laser-level fields of genetically engineered soybean to tiny hillside plots growing tumbles of traditional maize, bean, squash, and herbs, cultivated by hand" (Cleveland 2014, 72). Mary V. Gold (2007, under "Sustainable Agriculture: The Basic") of the USDA National Agricultural Library suggests that "sustainable agriculture" is a term that defies definition but provides "a sense of direction, and an urgency, that has sparked innovative thinking the agricultural world."

However, there are common themes among the many conceptualizations of sustainable agriculture (see a range of definitions in Table 1). The first, perhaps most common, theme is to feed humans a nutritional diet for a long or indefinite amount of time (Cleveland 2014; Conway 1998; Godfray et al. 2010). The second theme is that "sustainable" agricultural system must maximize environmental, social, and economic factors to achieve the goal of feeding people for a long, long time (Allen et al. 1991; Council 2010; FAO 2014; Duesterhaus 1990; *The Food, Agriculture, Conservation, and Trade Act (FACTA)* 1990). The third theme is that agriculture needs to be reframed as an intertwined natural and human system, typically called an agroecosystem (Altieri 2009; Cleveland 2014; Conway and Barbier 1988; Conway 1998; FAO 2014, 2018a; Gliessman 2015; Mollison 1988; Council 2010; Nesheim, Oria, and Yih 2015).

Table 1 Definitions of sustainable agriculture

Reference	Direct quote definitions of sustainable agriculture
Agroecology researchers Allen, Dusen, Lundy, Gliessman (Allen et al. 1991, 6)	"A sustainable agriculture is one that equitably balances concerns about environmental soundness, economic viability, and social justice among all sectors of society."
Australian "Chief Scientist" (Australia's Chief Scientist 2009)	"Sustainable agriculture is a simple concept that embraces a complex web of scientific and economic issues. Developments in information technology will play a key role in managing the complexity. To achieve sustainable agriculture, we must deal both with issues involving environmental impacts and productivity of the land. The farmer-focused agricultural organisations in Australia are working with researchers to develop farming systems that are both sustainable and profitable."
United Nations Food and Agriculture Organization (FAO 2014, 12)	"Our vision for sustainable food and agriculture is therefore that of a world in which food is nutritious and accessible for everyone and natural resources are managed in a way that maintain ecosystem functions to support current as well as future human needs. In our vision, farmers, pastoralists, fisher-folks, foresters and other rural dwellers have the opportunity to actively participate in, and benefit from, economic development, have decent employment condition and work in a fair price environment. Rural women, men, and communities live in security, and have control over their livelihoods and equitable access to resources which they use in an efficient way."
Richard Duesterhaus, President of the Soil and Water Conservation Society (Duesterhaus 1990, 4)	"At last fall's Agricultural Outlook Conference in Washington D.C., John Ikerd defined "sustainable agriculture" as those farming systems that are capable of maintaining their productivity and usefulness to society indefinitely. Such systems, he said, must be resource conserving, socially supportive, commercially competitive, and environmentally sound. For the adoption of crop rotation, integrated pest management, and the other components of sustainable agricultural systems, however incremental, holds the promise of improved soil erosion control, better waste

	quality protection, enhanced wildlife habitat, and a more acceptable quality of life generally for producers and consumers alike, not to mention its positive long-run consequence for such an important matter as the continuation of life itself on this earth."
US Legal Definition (Leahy 1990) defined in the 1990 US Congress "Farm Bill" (*The Food, Agriculture, Conservation, and Trade Act (FACTA)* 1990) Used also by the US National Research Council (Council 2010)	"The term "sustainable agriculture" means an integrated system of plant and animal production practices having a site-specific application that will, over the long-term— (A) satisfy human food and fiber needs; (B) enhance environmental quality and the natural resource base upon which the agriculture economy depends; (C) make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; (D) sustain the economic viability of farm operations; and (E) enhance the quality of life for farmers and society as a whole."
European Commission (European Commission 2013)	"Creating a sustainable agricultural development path means improving the quality of life in rural areas, ensuring enough food for present and future generations and generating sufficient income for farmers. Supporting sustainable agricultural development also involves ensuring and maintaining productive capacity for the future and increasing productivity without damaging the environment or jeopardising natural resources. In addition, it requires respect for and recognition of local knowledge and local management of natural resources, and efforts to promote the capabilities of current generations without compromising the prospects of future ones. Consequently, economic and environmental sustainability, adequate farmer incomes, productive capacity for the future, improved food security and social sustainability are important elements of developing countries' agricultural development."

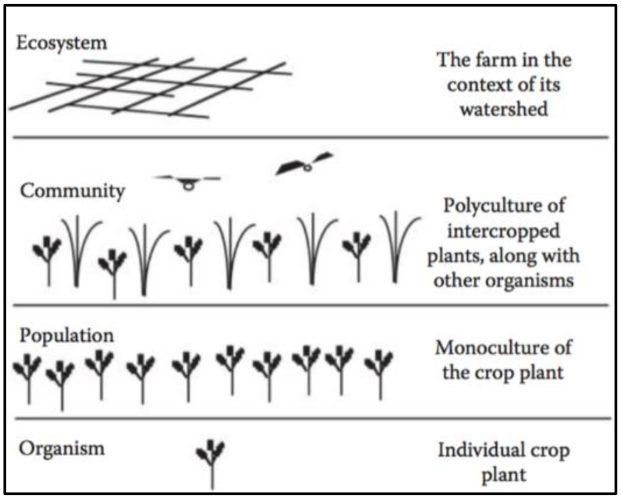


Figure 2-2 Levels of ecosystem organization applied to an agroecosystem as defined by Gliessman, (2015, 22).

Agroecosystems. Gliessman defines an agroecosystem (i.e., agricultural + ecosystem) as a site or integrated region of agricultural production understood as an ecosystem (Gliessman 2015). When considering levels of ecological organization (see Figure 2-2), Gliessman's interpretation of an agroecosystem is equivalent to an ecosystem composed of communities of living organisms and their environment, including all abiotic factors. In practice, an agroecosystem exists in and is inseparable from the spatially and ecologically larger landscape. Natural ecosystems and agroecosystems exist on a continuum of degree of human influence, where few, if any, natural ecosystems are completely void of human influence and agroecosystems vary in the degree of their human influence. Conceptually, boundaries of an agroecosystem are somewhat arbitrary because, as Gliessman states, "an agroecosystem is enmeshed in both social and natural worlds" (Gliessman 2015). However, in terms of management, there is typically a defined spatial boundary, like a farm. Anything that comes from off the farm is an *external human input*, apart from natural inputs like sun light. All things on the farm are a part of the agroecosystem and are managed, whereas things beyond the boundary are a part of the natural ecosystem.

Conway and Barbier describe agroecosystems as “a hierarchy ascending from the level of the individual plant or animal all the way to national systems linked by international trade” (Conway and Barbier 1988, 651). Their hierarchy differs from Gliessman’s in that it is not a literal comparison to that of a local ecosystem. Instead, it expands Gliessman’s concept of an agroecosystem by incorporating the social constructs of the agrifood industry. This conceptualization of agroecosystems necessitates that each level “be analyzed and developed both in its own right and in relation to other levels above and below” (Conway and Barbier 1988, 656). In this view, sustainable agricultural development cannot happen from farm-level research nor macro-economic policy alone.

Ecosystem Services. Like natural ecosystems, agroecosystems systems provide ecosystem services (Clark and Nicholas 2013; Nowak 2006; Konijnendijk and Gauthier 2006). The researchers that complied the Millennium Ecosystem Assessment define ecosystem services as “the benefits that people obtain from the ecosystem” (Millennium Ecosystem Assessment Program 2005, v). These benefits include provisioning services, regulating services, cultural services, and supporting services (see Table 2). For a comparison of Millennium Ecosystem Assessment’s categorization of ecosystem services to other categorizations, see (Costanza et al. 2017).

By utilizing and generating ecosystem services, sustainable agriculture can reduce or eliminate the use of resources that contribute to a significant percentage of greenhouse gas emissions, (e.g., chemical fertilizers, chemical pesticides, and fossil fuel burning equipment), resources that poison consumers (e.g., lingering carcinogenic pesticides), and resources that decline through crop production (e.g., water, crude oil, arable land) (Millennium Ecosystem Assessment Program 2005; Daily 1997).

Table 2 Ecosystem services as categorized by the Millennium Ecosystem Assessment Team

Category	Service
Provisioning	Food, water, timber, fiber, fuel
Regulating	Climate regulation, flood regulation, disease regulation, water purification
Cultural	Aesthetic, spiritual, recreational, educational
Supporting	Soil formation, photosynthesis, nutrient cycling

While the benefits of ecosystem services are recognized by scientists, the development of tools for valuation (i.e., estimation of worth) is still immature (Costanza et al. 2017, 2014; DeGroot 2014). The difficulty here is that historically policy and land use proposals were evaluated based on a financial value, but ecosystem services are difficult to value financially. Costanza and Folke (1997) argue that valuation of ecosystem services should happen on three levels – sustainable scale, fair distribution, and efficient allocation. While financial valuation can be aligned with the third level – efficient allocation – fair distribution and sustainable scale are more in line with community or societal preferences and whole system sustainability issues (Costanza et al. 2017).

Is Local Sustainable? Another characterization of sustainable agriculture, particularly among activist groups like many permaculture communities, is "local." Local agriculture can increase community resource security, public health, nutrition, social capital, and microenterprise opportunities (Clark and Nicholas 2013; Lovell 2010; Dubbeling et al. 2009). Not only food, but many essential goods used today like timber, fiber, medicine, household cleaners, etc., are or can be derived from local agricultural resources or byproducts. Growing resources locally helps a community achieve a certain amount of control over what they will consume, and the agricultural system that produces it – i.e., food and resource sovereignty (Campesina 2007; Tudge 2016; U.S. Food Sovereignty Alliance 2014). Locally grown resources also reduce or eliminate energy and other materials used in domestic and international transportation and storage, however, this is typically a very small percentage of a farm's total fossil fuel use and greenhouse gas emissions (Cleveland 2014, 246–49).

Transitioning to local agriculture and food systems in part addresses the underlying issue that people do not have much power over the food they eat or standards for how it is produced. American political economist Gar Alperovitz argues that by eliminating mechanisms for people to work together to achieve a common goal, like with unions and cooperatives, the wealthy minority has forced the poor majority into conditions where they have to operate and survive as individuals (Alperovitz 2017). He argues that this phenomenon is symptomatic of corporate capitalism and that US industrial agriculture is implicated in corporate capitalism. Alperovitz further posits "the design of corporate capitalism is unable to sustain values of equality, genuine democracy, liberty, and ecological sustainability as a matter of inherent systemic architecture" (ibid). Instead of corporate capitalism, he argues for the systemic design and construction of new institutions, especially locally, that support serious longer-term transformative politics because local institutions provide a context which allows and nurtures the sustained development of an alternative political culture. Among the new institutions Alperovitz describe are cooperatives, neighborhood corporations, land trusts, municipally owned energy and broad band systems, and hybrid forms of community and worker ownership.

Local sustainable agriculture institutions include grassroot cooperatives, neighborhood corporations, "permaculture guilds," farmers' organizations, and research extension agencies. Some of these institutions, such as cooperatives and community supported agriculture programs (CSAs), primarily work to exchange goods – an essential activity in security food and resource sovereignty. Others, such as permaculture guilds, farmers' organizations, and extension agencies, work to exchange knowledge. Agroecologist Keith Douglass Warner explains that social learning has become the chief strategy for extending more "sustainable" alternatives within conventional agriculture because expanding sustainable alternatives requires more exchange of knowledge than static expert knowledge or delivery of technology (Warner 2007). Warner argued that practitioner-led information generators such as farmers' organizations are critical because, in many cases, growers and farmers develop agroecological strategies and practices before agricultural scientists.

While "local" is a crucial component of sustainability, local institutions alone are not effective (Alperovitz 2017; Cleveland 2014; Conway and Barbier 1988; Godfray et al. 2010). Sustainable agriculture efforts must connect at regional and national levels to provide food items to people and places that have limited or seasonal access to certain varieties of food due to climate, land-use, or population reasons, and sometimes all three.

Alperovitz argues that achieving community sustainability, and thereby ecological sustainability, requires planning at a regional or national level because decisions made at larger scales can upend or negatively impact careful local planning (Alperovitz 2017). He describes this "Pluralist Commonwealth" vision as a system of public, private, cooperative, and common ownerships structured at different scales and in different sectors.

In the context of agriculture, a pluralist commonwealth requires mutual collaboration between grassroots sustainable agriculture efforts and municipal, regional, national, and global efforts such as those undertaken by the USDA and the UN Food and Agriculture Organization (FAO). The FAO is one example of an international institution looking to grow support for small-scale grassroots efforts in sustainable agriculture. At the 2nd International Agroecology Symposium in Rome (April 2018), FAO Director-General José Graziano da Silva argued that agroecology is a promising mechanism towards achieving the Sustainability Development Goals (SDG) (FAO 2018d). He said "to move forward, we need the engagement of more governments and policy makers around the word" (FAO 2018a). He emphasized that "scaling-up" this initiative must maintain the involvement of family and small-scale farmers (FAO 2018c).

The transition movement is one example of grassroots sustainable agriculture efforts attempting to work within a formal governing system. The transition movement is a social movement originally motivated by the permaculture social movement, aiming to promote sustainable living and build ecological resilience in the near future at local levels. A social movement is an informal network of people that share a collective identity and are aligned in their engagement of a political or cultural conflict (Diani 1992). People who identify as members of a movement participate individually or in small groups in activities characteristic of the movement and work towards addressing the conflict. Sometimes members of a social movement form an organized, typically co-located, community that are effectively communities of practice.

"Transition" is defined as "transforming the place you live from its current highly vulnerable, non-resilient, oil-dependent state to a resilient, more localized, diverse and nourishing place" (Hopkins 2011, 14). Transition towns across the world have collaborated with city councils and larger governments to create legislation in regards to climate change, peak oil, and more (Hopkins 2011). Rob Hopkins, the founder of the transition movement explains “the legal structure of a group affects its behaviour and how it is seen by others” (Hopkins 2011, 130). “Flexibility and informality,” Hopkins continues, “is fine for a young initiative, but as you grow and take on more responsibilities you will need more structure and allocation of responsibility” (Hopkins 2011, 130).

2.3.3. Agroecology

Agroecology is an agriculture practice and scientific field that applies ecology to agriculture (Lovell 2012). Agroecology integrates modern and traditional knowledge of agriculture systems, as well as social science and natural science, and emphasizes food sovereignty and social and biological diversity (Cleveland 2014, 169). Agroecology situates human systems within natural systems, eliminating the dualism as discussed at the start of Chapter 1. In building sustainable agroecosystems, agroecology models the structure of natural ecosystems but with human derived inputs and outputs.

Agroecology emphasizes environmental sustainability by mimicking natural systems via use of perennial polycultures (i.e., planting many species together as a system that lives for more than two years), reducing reliance on off-farm resources, avoiding synthetic inputs, minimizing toxic materials, conserving energy, and protecting natural resources such as soil and water (Magdoff 2007; Gliessman 2015). In comparison, industrial agriculture emphasizes monocultures (i.e., one species), often annuals (i.e., live for one season or year), use of synthetic fertilizers and pesticides, and heavy machinery to till, plant, and harvest. Snapp et al. (2010) have demonstrated that polyculture systems can compete with monoculture systems in terms of yield consistency, grain quality, production profitability, fertilizer efficiency, and farmer preference. Perennial crops (i.e., plants that live for more than two years), including trees, minimize disturbance of the system while providing additional benefits such as carbon dioxide uptake, soil stabilization, and microclimate control (Lovell et al. 2010). Natural and semi-natural ecosystem landscapes are ecologically more sustainable, economically more beneficial than converted systems (e.g., crop land), and are socio-culturally preferable (de Groot et al. 2010).

Maintaining economic sustainability remains a challenge for mainstream agroecology practitioners. For many existing farmers and ranchers, rapid conversion to agroecosystems is not financially practical or possible, so conversion efforts tend to proceed slowly (Gliessman and Rosemeyer 2009; Nagothu 2016). Most farms stall at early stages of conversion because of the initial reduction in yield and loss of profits. The farmer's inability to adjust the economics of the farm's operation to the new relationships that come from farming agroecosystems, and farmer doubt of the productivity of an agroecosystem in comparison to traditional monocultures, leads to giving up on the conversion (Gliessman and Rosemeyer 2009; Lovell 2016).

Scientific validation of agroecosystem practices is also challenging. Martin and Isaac (2017) argue that "agroecology lacks a theoretical framework for the development and testing of general hypotheses." Agroecologist Sarah Taylor Lovell and her research team have just established what is believed to be the first "production size" field trial that compares an agroecosystem to the traditional soy and corn rotation in southern Illinois

Figure 2-3 Agroforestry for Food at University of Illinois (Lovell et al. n.d.).

(Lovell 2016; Lovell et al. n.d.). The 30-acre experiment at the University of Illinois has seven treatments, each repeated three times (Figure 2-3). At the time of this writing, the experiment is too young to have any preliminary or conclusive results. Such an experiment takes many years to complete, making scientific validation of agroecological practices a slow process.

Mainstream agroecology is facing challenges regarding social sustainability among farmers and consumers. Not unlike modern industrial agriculture, the start-up costs for agroecosystems can be unobtainable as they often require continued education, high-quality inputs(e.g., organic materials, not synthetic) and infrastructures (e.g., water recycling and reclamation systems), new or different equipment (e.g., tractors), and investment in mature plants to reduce time to yield (Nagothu 2016; Warner 2007; Gliessman and Rosemeyer 2009). Unlike conventional agriculture, there are few subsidies and financial programs to support farmers transitioning to sustainable agriculture methods. Because professional agroecosystem crops are novel and in comparatively small supply to conventional crops, their high price prevents the product from being equally available to all consumers (Gliessman and Rosemeyer 2009; Tudge 2016).

Social learning is a critical factor in farmers' adoption of agroecology. Warner (2007) criticized the lack of social learning among researchers, extension agencies, and farmers. Note that in this context, social learning denotes participation as a group in experiential research and knowledge exchange to enhance common resource protection (Warner 2007; Woodhill and Röling 1998). Ollivier et al. (2018) argue that social learning must engage with the plurality of ontologies, knowledge, and power distribution to effectively support agroecological transitions.

Social learning networks are necessary for understanding local ecological conditions and deriving techniques that are regional and social-infrastructure specific. In the United States, land-grant universities and colleges share new research with and provide education to farmers and other residents in their local area through National Institute for Food and Agriculture supported institutions called extensions (Talmadge 1977). Post-Green Revolution, Warner (2007) argued, most extensions focused on “transition of technology” with the prospect of increasing yields, giving little thought to the systemic effects that technology has on the farm. Warner (2007) attributed farmers’ slow adoption of agroecology to a decline in governmental funding in the late 1980’s and early 1990’s (National Research Council 1995) and private investment in extension services by conventional agriculture stakeholders (Rivera and Cary 1997). However, a recent effort in the Northwestern United States to redefine extension proprieties to address climate change (Yorgey et al. 2017) and state-funded research in sustainable agriculture (UCANR 2018) demonstrates that trend is changing.

In contrast to industrial agroecology, grassroots agroecology largely operates outside of the markets, standards, and regulations of mainstream food and agriculture systems, and is thus able to overcome some of the socio-economic challenges professional agroecology faces. For example, grassroots agroecology is typically growing at a small scale for a personal use or a small, often informal market, and so does not have large operational and distribution costs. Grassroots agroecology movements emphasize localization, which dictates that environmental and social goals constrain economic goals (Cleveland 2014, 238). According to Cleveland, localization seeks to close three spatial and structural disconnects of mainstream agri-food systems (Cleveland 2014, 235):

(1) between the places were food is grown and where it is eaten,
(2) between the places where food is grown, processed, transported, and consumed and the places where the resources used are from, and
(3) between eating food and its fundamental roles of biological, physiological, and cultural nourishment.

Addressing localization in only some of these ways will not yield a functioning grassroots agroecology because only marginal changes would occur. In Cleveland's case study, farms in Santa Barbara County (SBC) annually produce nine times more fruits and vegetables than the population consumes, but less than 4% of produce consumed in SBC comes from within the county (Cleveland 2014, 246–49). The case study demonstrated that complete localization of fruit and vegetable consumption in SBC, without any changes to farming production practices, would have a marginal reduction of greenhouse gas emissions. This was an unsurprising finding for Cleveland and his team given that "food miles" account for only 2.5% of total agrifood system greenhouse gas emissions (Weber and Matthews 2008). Cleveland, however, did suggest that a holistic localization effort, one that addresses the three spatial and structural disconnects, has great potential to improve nutrition and access to fresh fruits and vegetables for the 39.5% of the SBC population that was food insecure. Cleveland concluded that more research is needed on “how localization can be accomplished in a way that directly supports the underlying goals of grassroots localization advocates” (Cleveland 2014, 250).

Food sovereignty, social learning, and moderate market values are all ways that grassroots agricultural movements can support the mainstream agroecology discipline. Agroecology has particularly gained traction in the permaculture movement (Ferguson and Lovell 2013, 2015b). Through social learning, permaculture draws amateur farmers and gardeners into agroecosystem practice, effectively putting the power to grow and access food sustainably into the hands of the people. Many amateur permaculture gardeners are turning professional and producing a new wave of farmers, most of which are young and practice in urban or suburban settings and sell their product locally.

2.3.4. Ethnobotany and Traditional Agriculture

The term “ethnobotany” was coined by J.W. Harshberger in the late 19th century to describe botanists’ study of how indigenous people used plants in their local contexts. Ethnobotany research dates back as far as the 15th century when Europeans began colonizing the Americas (e.g., (Fewkes 1896; Harshberger 1896)). Midway through the 20th century, anthropologists expanded the field of ethnobotany when they began to study how human societies, particularly those that were preliterate, understood and classified plants and animals (Berlin 1992). It became a point of fascination to ethnobiologists that non-industrialized communities of people were able to control “an extensive body of knowledge akin to the scientific fields of botany and zoology” (Berlin 1992, 7). Beginning in the 1940's, the ethnobotany scope of study gradually expanded from indigenous people to include the study of the relationship of all humans with plants, particularly in a local context (Cotton 1996). For example, Ford argued that *folk knowledge* is held even by middle class Americans that maintain their yard (Ford 1978). Folk knowledge, sometimes called traditional knowledge, refers to what "local people know about the natural environment," which can be contrasted to scientific knowledge which is information derived from rigorous research using formal methods (Cleveland 2014, xxiv).

The study of ethnobotany has been integral to food sustainability research and activism since the advent of agroecology in the 1970's. Human ecologist David Cleveland suggests that integrating traditional knowledge, technologies, and mindsets, particularly in the form of sustainable agroecosystems, is the best way to address a global food crisis in which the human carrying capacity (HCC) of Earth is reached or exceeded (Cleveland 2014). The HCC is the amount of humans that can be supported indefinitely in a given environment without permanently damaging the ecosystems upon which we depend (Rees 1992). Researchers argue that traditional agriculture (i.e., pre-industrial) methods, specifically polycultures and local varieties, have comparatively greater biological diversity and annual yield stability to modern industrial farming methods (Altieri 2004; Cleveland, Soleri, and Smith 1994). Traditional agriculture favors polycultures that facilitate nutrient cycling among plants and other inter-plant supporting services (Vandermeer 2011, 1992) and local varieties that better withstand local environmental conditions (Francis 1986). Researchers hypothesize that comparatively resilient nature of traditional agriculture reduces financial risk and lessens environmental impact (Cleveland, Soleri, and Smith 1994; Cleveland 2014). Sustainable agroecosystems build upon traditional agriculture's localized context, including cultivated seed varieties passed down from generations, and techniques, like the use of polycultures to increase biodiversity and limit resource input (Cleveland 2014). Perhaps most significantly though, those who partake in sustainable agroecology maintain a perspective that traditional farmers have and is opposite to mainstream farming – that resources are limited (Cleveland 2014).

Ethnobotany has also been foundational to community development and food sovereignty programs world-wide. In the grassroots activism sector, ethnobotany was foundational to permaculture, as early pioneers Bill Mollison and Dave Holmgren drew upon the practices of Aboriginal Australians and Native Americans. In the institutionalized activism sector, the United Nations Educational, Scientific and Cultural Organization (UNESCO), The World Wide Fund for Nature (WWF), and Royal Botanic Gardens, Kew jointly formed the People and Plants Initiative (Cunningham 2001) in which traditional knowledge was applied in conservation, rural development, and other domains relating to wild plant use and resource management. In programs under this initiative, the value of plants in a local setting, the scarcity of the valued plants, and the cultural factors underpinning control of access to land or resources are determined and used to generate a "green social security" for local inhabitants in a global economy without collapsing the local ecology (Cunningham 2001).

2.4. Permaculture Context

Permaculture is a social movement and design ideology that applies the concept of structural and functional permanence to agriculture (i.e., permanent + agriculture = permaculture). Permaculture founder Bill Mollison first described permaculture as "an ecological design practice that aims to integrate landscape and people to provide for their own food, energy, shelter, and other material and non-material needs in a sustainable way" (Mollison 1988, xi). Permaculture has since explored social systems necessary for sustainable human settlements such as alternative economic systems and other social infrastructures.

At the foundation of permaculture methods are ethics and principles for a "conscious" design practice (Holmgren 2002; Mollison 1988; Mollison, Holmgren, and Barnhart 1981). Conscious design denotes the intention of designing for self-reliance and functionality of the all-encompassing (i.e., human and other natural) ecosystem. The ethics and principles have significant social implications for participants who structure their identities, work, and personal lives around them, which are reflected in their guiding pictorials and narratives.

Permaculture pictorials and narratives have a shared theme of coupled human and natural systems in which agriculture functions. A popular permaculture mandala (Burnett 1999) depicts a ring of systems centered around or supporting human activity, lush with productive foliage and food, set within the natural environment to emphasize that human systems are a part of the natural environment (see Figure 2-4). The shown human-supporting systems mimic nature and attempt to include technologies that are not resource-intensive. An "autonomous" home has a green roof, a small wind turbine, a small solar array, and a rain barrel. A classroom of children is small and personal, with multiple instructors for few children, and features ecological educational content. A green cityscape has people commuting by bus and bicycle but not by car. On the street there are recycling centers, window and greenspace gardens, and solar panels on roofs. A farmer's market is shown as a place for a thriving local economy, where farmers and patrons of many cultures gather and buy or sell fresh local food and products. A community garden has a gardener in a wheelchair working at a raised bed, demonstrating the importance of creating community facilities services that are accessible to everyone's needs.

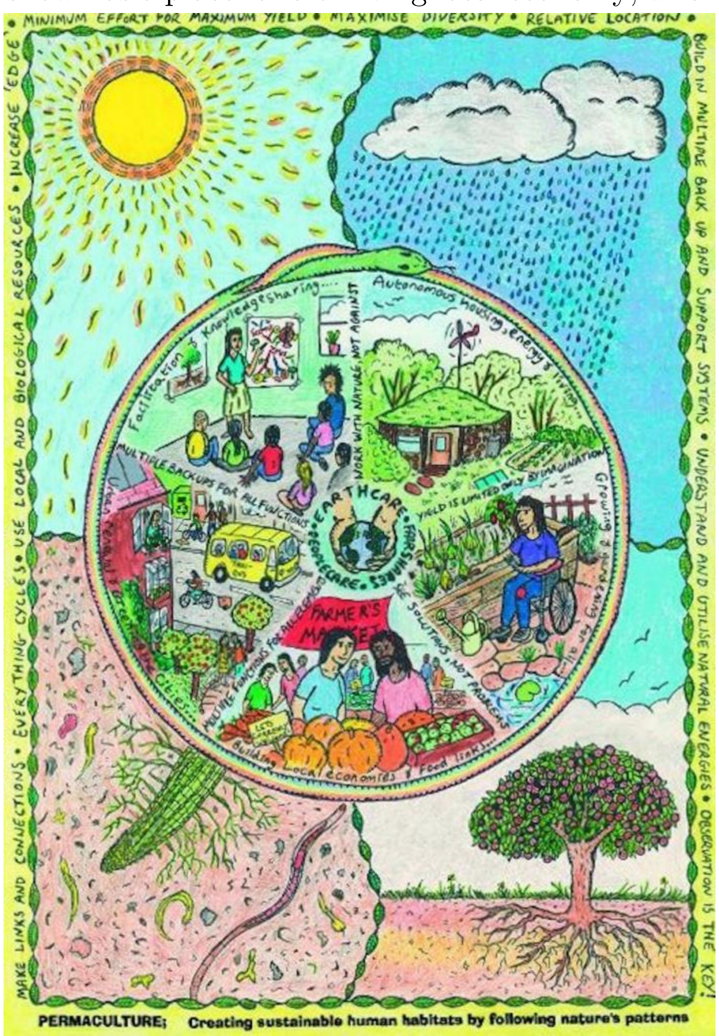


Figure 2-4 Permaculture mandala (Burnett 1999).

At the center of the human systems are the core permaculture ethics: earth care, fair share, and people care. Between the human systems, around the human system ring, and framing the natural systems containing the human systems, are principles and values that drive the permaculture design of sustainable agriculture to obtain these coupled natural and human systems, including: everything cycles; use local and biological resources; maximize diversity; build in multiple back up and support systems; work with nature, not against it; and multiple functions for all elements.

Permaculture narratives of sustainable agriculture are often situated in suburban and urban areas. In her 1994 novel *Fifth Sacred Thing*, Starhawk described San Francisco in 2049 as a sustainable human settlement following an earlier environmental collapse (Starhawk 1994), reflecting permaculture values and ethics. In this work, a resident of a newly ecotopian San Francisco reflects on the seemingly bountiful nature of her home: "You'd think we had plenty of everything, plenty of land, plenty of water. Whereas we've simply learned how not to waste, how to use and reuse every drop, how to feed chickens on weeds and ducks on snails and let worms eat the garbage."

In reality, the agroecosystem aspect of permaculture is typically a practice of grassroots communities of amateur gardeners and professional farmers. These communities build local food cooperatives and farmers' markets (Norton 2015), create infrastructure and norms for social learning (Gui and Nardi 2015a), and even introduce alternative currencies (e.g., the Totnes pound) or time exchange programs (e.g., Ithaca hours) to open participation opportunities to anyone and everyone (Gui and Nardi 2015a; Hodgson, Hopkins, and Transition Town Totnes 2010).

2.4.1. Permaculture Process

Broadly, permaculture "is a [process] of assembling conceptual, material, and strategic components in a pattern which functions to benefit life in all its forms" (Mollison 1988). In practice, a permaculture system is an ecological system that produces something beneficial to humans in a self-regulating manner (Hemenway 2009). Many permaculture participants work to design, build, and maintain permaculture systems. Other participants work to support their peers in that effort through supportive activities such as education, fund raising, providing or creating legal support, and building markets for their products. While each of these roles are critical to the participating communities of practice and information ecologies, this dissertation specifically seeks to support the permaculture participants that are designing, building, and maintaining the permaculture systems.

The permaculture process has been practiced in many similar but distinct ways. In conversation, participants often conflated design and the permaculture process, but in effect design is one part of the permaculture process. Here I provide an overview of the permaculture process in five steps (see Figure 2-5): (1) Needs Analysis, (2), Site Analysis, (3) Design, (4) Implementation, and (5) Maintenance. These steps represent the permaculture processes of the participating communities. However, each of these steps were and can be executed in a variety of ways.

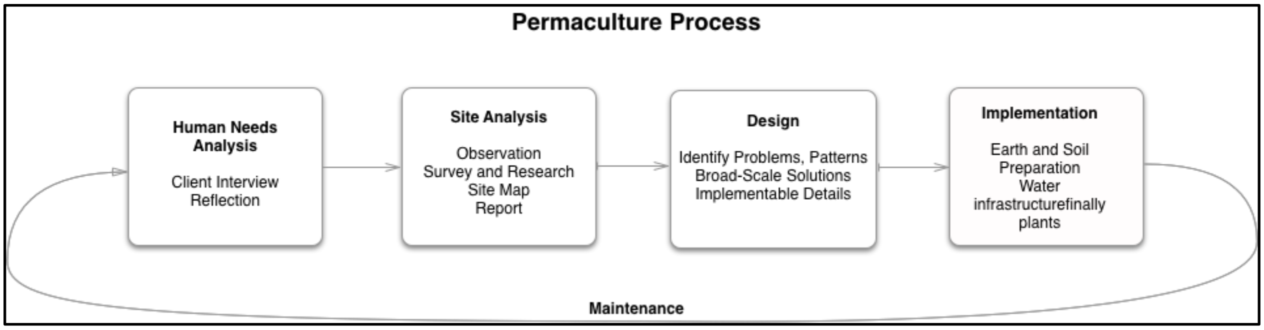


Figure 2-5 The observed permaculture process in this research.

Needs Analysis. A needs analysis forms a subset of the requirements for a permaculture system. This section focuses on user-imposed requirements for the permaculture system. Users of a permaculture system could be an individual, family, or a group. No matter the user, the requirements for the context in which the system will exist (e.g., community needs and restrictions) must also be determined so that the design is not rejected based on a technicality.

Client Interview. A client interview is necessary when a permaculture designer or student has been commissioned or has volunteered to create a permaculture design for someone else, including an organization. A permaculture designer interviews their client or a representative of the clients to determine what it is they want from their permaculture system. The designer's goal is to thoroughly understand the client's vision so that she can produce something the client needs and wants.

Designer Reflection. When the designer is creating a permaculture system for herself, she should engage in an activity similar to a client interview to determine the human-imposed needs of the design. She should systematically define her vision and goals for her permaculture system, so she can systematically engage in the remainder of the permaculture process. Opting for an open ended, spontaneous implementation of a permaculture system, instead of defining concrete goals for a personal use permaculture system, leads to designs that are overly complex and lack cohesion. Such unplanned implementations risk wasting resources such as time, money, and ecosystem services.

Site Analysis. A site analysis uses observation of the site and environmental data research to form a site survey report, which includes a base map and a sector map (see

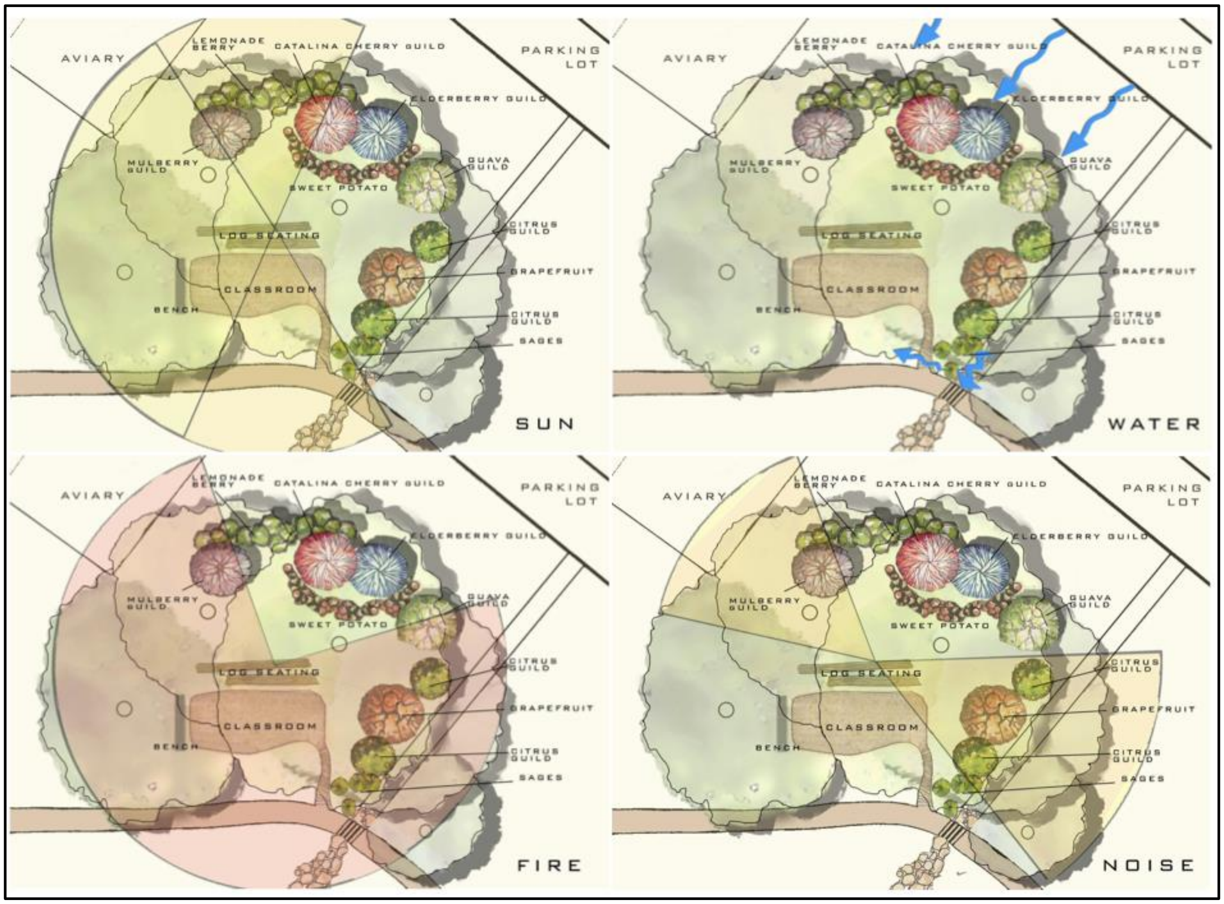


Figure 2-6 Sector maps of the UCI Arboretum used with permission by a group in Manzanita PDC-2015.

Figure 2-6). This team demonstrated the path and exposure of the sun, the flow of the water, the direction which fire could originate, and the direction which noise came from. These data are presented on separate diagrams, but some designers prefer to demonstrate these factors on the same diagram.

Observation. Observation is both a passive and active activity. During passive observation a designer watches, listens, and smells the environment for which he is designing without physically manipulating anything. Passive observation enables the observer to experience the environment without disturbing the environment. During active observation a designer physically engages with the environment to explore the things they noticed during passive observation. A designer may feel the soil, taste a fruit, or pick up a log to observe what is underneath. Observation can follow a client interview and therefore be directed by the client's requirements or be open-ended when it precedes a client-interview. Observation and the client interview produce the primary design requirements for the project.

Construction of Artifacts. The product of a site analysis is a site survey report, which includes a base map, a sector map, and a text explanation of the map information and additional details not suited for representation on a map (e.g., history of use of the site). The base map represents a blueprint of the site. While the information on a base map may differ between projects, it typically shows existing man-made structures (e.g., buildings, concrete slabs, sheds, etc.), existing plants (e.g., trees, turf, etc.), and topography. The sector map (Figure 2-6) features phenomena that occur at the site that should be kept in mind when designing. For example, a sector map may specify zones of activity (i.e., zone 1 is most frequently visited, zone 5 is considered undisturbed nature) (Mollison 1988), good and bad views, prevailing seasonal winds, areas of erosion and flooding, seasonal sunlight exposure, and similar items.

Design. This is the point when a designer switches from understanding to creating. A designer ensures that design elements are placed in such a way that "each serves the needs and accepts the products of other elements" (Mollison 1988, 37). "The problem is the solution" is one of three proclaimed cornerstone principles to permaculture design by Bill Mollison (Mollison 1988, 15), representing the adage that the solution to a problem lies within the problem itself. Determining how to address a problem and turn it into a solution requires the designer to engage in *functional* design. For a design to be functional "every component ... should function in many ways and every essential function should be supported by many components" (Mollison 1988, 69). Such a design is generated broadly then refined down to the details. This is known as the principle "design from patterns to detail" (Holmgren 2002, 127). While the detailed, implementable design may change over time with respect to implementation concerns, the broad-scale design establishes the overall vision of the client.

Broad-scale versus Implementable Design. A broad-scale design specifies design elements and their functionality at a high-level. For example, a rain water collection tank will feed a fruit-tree polyculture, but the type and size of the water tank nor the plants in the polyculture will be specified. In contrast, implementable designs are typically complete with plant lists and other specifications like measurements for berms and swales (Weiseman, Halsey, and Ruddock 2014).

Implementation. Implementation is the point in which a permaculture design is translated from paper into the environment. For a permaculture system to be manifested as it was designed, the implementer needs to understand the intimate details of how the elements of the design work together or needs a thorough set of instructions of how to implement it. Some designs will provide instructions for implementation order like, for example, planting pioneer crops to prepare the soil for what is to come next. However, no design tells one how to, for example, put a particular plant in the ground because basic gardening skills of the implementer are assumed. Both a high-level understanding of how to implement components of a design and a low-level understanding of how to install the design is critical for the design come to fruition.

Maintenance. Maintenance is a continual process after the design is implemented and includes harvesting. In practice, maintenance is the cyclical manifestation of the permaculture process. In permaculture, the beneficiary of the agroecosystem is typically the maintainer. It requires on going assessment to identify problem points and re-design then implement solutions. Re-designs are typically informal and often experimental.

2.4.2. Permaculture Education

For communities of practice to persist, they must grow via the introduction of newcomers. Lave (1991) argues that learning is the process that a newcomer undergoes to become a full participant in a community of practice. It involves the formation of an identity as a member of the community and mastery of knowledgeable skills required to engage with and contribute to the community.

Amateur gardeners and small-scale farmers are easily drawn to permaculture, but for those who do not have experience growing plants the barrier to entry is quite high. In his 2015 talk at the *Permaculture Voices 2* (PV2) conference, a nationally focused permaculture conference held in March 2015, permaculture educator Dave Boehnlein argued that two of the primary barriers to entry for newcomers are a $1500 introductory course and Mollison's *Permaculture: A Designer's Manual* (Mollison 1988), which he referred to as a "500-page bible of dry information" (Bloom and Boehnlein 2015).

From its beginning, the Permaculture Social Movement has supported a two-phase model for the introduction of newcomers and their maturation into full participants of local communities of practice. Since 1981 (Mollison 2001), the primary way of introducing newcomers into a permaculture community of practice was through a didactic Permaculture Design Certificate Course (PDC), after which they engaged in an apprenticeship to become full participants of the community (Cloutier and Sontoya 2013). A PDC provided the newcomer with a comprehensive view of the ethics and design principles of permaculture, and the apprenticeship provided the opportunity for newcomers to form the skill required to be a competent member of the community.

Wenger (2008) argues that communities of practice evaluate competence to determine if a newcomer should be considered a full participant. Wenger further explains that communities define competence through a joint understanding of what the community is about and hold each other accountable to contributing to it. The joint understanding and expectation to contribute to the community evolves from the mutual engagement in building (and evolving) the community. A particular repertoire of language, routines, tools, etc. is formed in the community, and a competent member should have access to it and use it properly.

How competence is evaluated varies greatly between communities of practices and is often not a formal process. Instead, competence may be measured informally during interaction with a person and is subject to influence by reputation among the community. For many permaculture communities today, the two-phase model of completing a PDC followed by apprenticeship is no longer the typical way newcomers are introduced to permaculture. Instead, many newcomers do not engage in an apprenticeship after completing a PDC. Some PDC instructors set the expectation that completing a PDC is enough to engage in permaculture as a full participant. The modern PDC is a seventy-two instruction-hour course, introducing topics regarding permaculture principles and ethics, food, waste, energy, water, and shelter. Students engage in design practice and some hands-on implementation activities of selected permaculture elements. The amount of time it takes to complete a PDC varies greatly, meaning the 72-hours of instruction time may be completed in one week or three months, and the details of the instruction often cater to the local climate and social norms. As more communities emerge with or adopt lower standards for competence, the permaculture movement may grow in population, but it is unclear if it is an effective model for increasing permaculture's impact on the world.

2.4.3. Limitations of Permaculture

Like agroecology, permaculture also has a set of limitations – a lack of diversity, a lack of size and impact, a lack of precision in practice, and high barriers to entry, as described in the previous section. Permaculture farm operators in North America are predominately middle class, white, and male (Ferguson and Lovell 2017), thus it has not significantly increased the diversity of farm operators in the US agricultural system as reported by the United States Department of Agriculture (USDA) – i.e., 96% white (USDA Census of Agriculture 2012a), 70% male (USDA Census of Agriculture 2012b), and 62% middle class or higher (USDA ERS 2017b). However, permaculture farmers are younger and newer to farming than average, and more are first generation farmers compared to farm operators in the traditional US agricultural system (Ferguson and Lovell 2017).

Although permaculture attracts those from a high standard of living seeking to live more moderately, it lacks appeal to those who are struggling to meet their basic needs. However, these issues of diversity may be slowly changing as permaculture is adopted in urban areas that have seen economic decline or natural disaster, like earthquakes in Haiti (Gans 2010). For example, in 2013, the city of Detroit, Michigan filed for bankruptcy following a decades-long financial decline propelled by the decline of its automobile industry (Steinmetz 2009). Today, it still has a poverty rate of 39.4% (US Census Beureau 2017). In addition to empty lots and vacant homes, Detroit is now also characterized by urban agriculture (Hebert 2016; Dubbeling et al. 2009; Walker 2016). The people of

Detroit have used permaculture and other urban farming techniques to grow food, rehabilitate contaminated soil, restore forest habitat, and create businesses (Eidt 2012; Giorda and Lowe 2015; Hebert 2016; Walker 2016). These acts have provided residents with a socio-ecological connection with their community, which may have a positive effect on mental health and crime rates (Hoffman et al. 2016; Giorda and Lowe 2015). More recently, however, local journalist Tom Perkins (Perkins 2017) argues the exemplary Detroit urban farming movement has been challenged by colonialism as white people attempt to start large projects that give away free food in predominately black neighborhoods. Perkins questions, “Should [the Detroit urban agriculture movement] aim to improve food security, strengthen local economies, provide jobs, and empower longtime residents? Or is it about giving away free food?”

The permaculture movement has historically been small relative to mainstream agriculture. At PV2 I observed the permaculture community’s energized discussions about the necessity of introducing more people to permaculture. One central argument for making an effort to introduce permaculture to a wider audience was that the permaculture movement and its participating communities would not make a significant impact on the world without more participants (Bloom and Boehnlein 2015). The conference publicized projects demonstrative of permaculture’s success, such as Geoff Lawton’s (2016) *Greening the Desert* project in Jordan and Paul Wheaton’s (2016) permaculture homestead education center and community, *Wheaton Labs*, in Montana. The conference also showecased projects that align with permaculture but do not necessarily call themselves permaculture, such as the Global Village Construction Set (Jakubowski 2014) and Stamets' work on fungi for bioremediation and medicine (Stamets 2005) at PV2. The movement believes that increasing the number of people participating will lead to more projects, and thus more success and social acceptance.

Permaculture has not traditionally followed scientific methods nor engaged with scientific research. Unafraid of experimentation, permaculture practitioners show a huge amount of creativity and develop novel solutions to unusual problems. Unfortunately, sometimes these experiments can lead to unintended adverse effects, such as unknowingly introducing an invasive species to an environment. Consequentially, the permaculture movement has been criticized for being too idealistic and a "pseudoscience" (R. Scott 2010; Chalker-Scott 2010). More recently, however, Ferguson and Lovell attempts to bring in the strengths of the agroecology discipline and permaculture movement together to address areas where each is lacking (Ferguson and Lovell 2015a; Ferguson 2014a, 2014b; Ferguson and Lovell 2013), such as encouraging permaculture to adopt norms of formal social learning such as more rigorous evaluation and feedback, and engagement with other agricultural disciplines.

In the next chapter, I will be discussing my experiences in two permaculture communities and the challenges the communities faced when engaging in a range of sustainable agriculture practices.

CHAPTER 3:

Research Context

This chapter describes the communities that participated in this research, the methodology of the research interactions I had with the community, and the data analysis used to determine the communities' information challenges, values, long-term design scenario, and requirements for the SAGE Plant Database.

3.1. Participating Communities

Throughout this dissertation I discuss two participating communities. Both communities were in the United States, one in the humid subtropics of the Southeast coast and the other in the Mediterranean climate of the Southwestern coast. To protect the privacy of these communities and the participants in this research they will be referred to as the Live Oak and Manzanita communities, respectively, after prominent trees from the local ecology. I also refer to these communities' geographical locations as Live Oak and Manzanita, however, these are not the true names of these geographical locations.

Both permaculture communities were forming when this research began. People typically explored their interest in permaculture by attending an annual introductory course on permaculture design (i.e., a PDC). The people interested enough in permaculture to attend a PDC or otherwise engage in the community were either members of the established, though not formally organized, grassroots sustainability communities in their local areas or newcomers to both. They came from a variety of backgrounds including college students, farmers, restaurant owners, medical professionals, landscape designers, computer scientists, parents, and school teachers. However, they were unified in their interest in learning how to live and lead more sustainable lives and particularly interested in exploring sustainable agriculture from the perspective of permaculture.

The first phase of my research (see Table 3) was with the Live Oak community during the 2011 PDC, henceforth known as Live Oak PDC-2011. I engaged in Live Oak PDC-2011 as a student. I engaged as a participant or volunteer in other community activities, such as planting community gardens or tabling at city festivals, concurrent to attending the 2011 Live Oak PDC season. The second phase of this research occurred in 2012 including the Fall 2012 Live Oak PDC (henceforth known as Live Oak PDC-2012). During the second phase I was a participant of an on-going apprenticeship, a volunteer for many community activities, and a facilitator of Live Oak PDC-2012. The third phase of this research was in 2014 with the Manzanita community, including their Spring 2014 PDC (henceforth known as Manzanita PDC-2014), during which I was a facilitator. The fourth phase was primarily a requirements inquiry and occurred 2015-2018 during which time I served as a volunteer and participant for community activities, but no longer a facilitator in the PDCs. The Live Oak and Manzanita communities were unaffiliated and outside of my involvement in these communities, they do not, as far as I am aware, share members.

Table 3 Research phases mapped out by year, community, and activity

Research Phase	Year	Community	Activities
1	2011	Live Oak	Student in Live Oak PDC-2011 Hosted action-research workshop Observing participant in community activities
2	2012	Live Oak	Facilitator in Live Oak PDC-2012 Observing participant in community activities
3	2013-2014	Manzanita	Facilitator in Live Oak PDC-2014 Observing participant in community activities
4	2015-2018	Manzanita	Hosted action-research workshops Observing participant in community activities

3.1.1. Live Oak Community

The Live Oak permaculture community existed within a larger metropolitan grassroots sustainability activism community, along with a local food cooperative, an organic grower collective, a simple living institute, a holistic medicine school, a university arboretum, and several small sustainability-oriented businesses.

The permaculture faction did not contain a distinct member group from the rest of the sustainability community. Devoted members of the permaculture faction, often self-described as "permies," were often involved in other Live Oak sustainability activism. "Permie" is a term informally used throughout the permaculture movement to distinguish full participants from the peripheral, and sometimes uncommitted, participants in a permaculture community. The permaculture community founder participated in the local food cooperative as a farmer. Some permaculture participants and students were also students of the local holistic medicine school. Sometimes these interactions were partnerships. For example, the permaculture founder hosted workshops at local businesses, such as a rain barrel installation demo at nearby a sustainable food restaurant. Participants of the greater grassroots sustainability community supported the permaculture faction even though they themselves were not participating. For example, a local farmer waved admission to his workshop about raising chickens for students in the permaculture course.

The permaculture community was initially centered around the founding instructor of the local PDC. The community was approximately one year old, having started the previous year with a PDC, when I became acquainted. In the following years, the once-pupils of the founding instructor practiced and became new instructors or service providers for the community. They moved from peripheral participants to full participants with knowledgeable skills, a development that Lave explains is difficult to achieve (Lave 1991). Lave explains that becoming a full participant is hinged on empowering socialization of the participant by the old timers and the willingness of the participant to adapt his or her perspectives to those of the community.

By 2013, the Live Oak permaculture community grew to over fifty full participants. A few of the full participants started consultation LLCs, and permaculture installments began popping up in the local area. Some participants focused on establishing home permaculture gardens. Some of the more complex implementations, both residential and civic, became community demonstration sites for using specialty systems in permaculture, such as grey water reclamation, rainwater catchment, and aquaculture. One participant created a permaculture-based elementary-school curriculum and garden.

This permaculture community also partnered with other permaculture communities. In 2012, several members of the Live Oak permaculture community worked with a community in another South Eastern state to revamp a permaculture garden at an eco-hostel – a lodging destination that supports ecotourism. In late 2012, the Live Oak permaculture community partnered with another regional permaculture community on an excursion to South America to build bamboo structures at another eco-hostel. In 2013 and 2014 this community hosted the statewide permaculture convergences (i.e., a community building conference).

3.1.2. Manzanita Community

This sustainability community is located within a predominately affluent suburban area within a greater metropolitan area.

One previous resident explained that a small permaculture community had existed five to ten years earlier. Although a number of permaculture members from this era remained in the area, they were either autonomous or focused on their own sustainability-oriented, but not permaculture branded, organizations. When the previous leader left, the previous resident explained, the local permaculture community of practice fizzled out – a result of when too few peripheral participants become full participants and none desires a leadership role (Lave 1991).

Lave and Wenger characterize the success of communities of practice as groups of people that have “reproduced” by engaging newcomers in apprenticeships in which newcomers learn through legitimate peripheral participation of a practice that is happening in its normal context (i.e., a situated activity) (Lave and Wenger 1991). More specifically, a newcomer engages in the practice (i.e., legitimate participation) alongside a full participant, thus being able to observe the full participant’s practice (peripheral participation) and learn from it. At first newcomers engage in simple tasks, but as they observe and work alongside the old-timer they take on more advanced tasks, until eventually they become full participants of the community (Lave 1991).

The sustainability education center that I partnered with re-initiated the effort to establish the permaculture community of practice. It did so by offering a PDC for four consecutive years. Despite more than forty-five students attending PDCs over four years and the collaboration of other permaculture communities, the permaculture community continued to struggle to foster the transition of newcomers into full participants. Although I cannot definitively explain why this was the case, there are a few conditions that I believe contributed.

First, many students were often transient, many leaving the region right after their PDC for work or school-related reasons, and so they were not able to engage in legitimate peripheral participation in the permaculture practices beyond the short-term PDC education. Second, several students in each PDC were employees or established volunteers at the hosting sustainability education center and concentrated their participation in the context of that organization and the larger grassroots sustainability community rather than continued legitimate peripheral participation in the permaculture faction. Third, although the education center offered the PDC, "permaculture" was not part of its branding, and so the leaders were not focused on providing continued education specifically for permaculture. Fourth, many instructors were guests from other, somewhat distant, communities, introducing distance as a barrier for newcomers to engage in legitimate peripheral participation outside of the sustainability education center (Olson and Olson 2000).

In the time since the fourth PDC in 2016, a permaculture community has formed beyond the sustainability education center, which has increased the opportunities for newcomers to transition to engage in legitimate peripheral participation. Most of the small but growing number of leaders and full participants do have prior affiliations with the center, either as staff or students of that PDC. Very recently (2018) these new leaders hosted several PDCs and other community meet-ups at multiple institutions, thus building the potential to grow and reproduce the permaculture community of practice.

3.1.3. Permaculture Design Courses

The primary way newcomers became participants in these communities was through PDCs. A PDC course is 72 standard instruction hours and focuses on design concepts such as sustainable, perennial polycultures that mimic ecosystems and provide ecosystem services. Obtaining this certification offers status within the movement. I have met permies from communities across the world, and their most common questions are, “when did you do your PDC” and “who was your instructor?” Having recently taken a PDC implies that you are a newcomer to the community, whereas having a well-known PDC instructor demonstrates the pedigree of your education.

Live Oak PDCs generally met one weekend day for eight consecutive weeks. Manzanita PDCs met two weekend days every two or three weeks over the course of 2.5 months. Most class sessions followed a schedule similar to the one found in Table 2.

Table 4 Single day class schedule for PDC2012 - shelter day, on-site

Time	Activity
8:00-8:30 am	Breakfast (optional, provided)
8:30-9:00 am	Opening circle
9:00-10:00 am	Lecture about shelter
10:00-10:15 am	Break
10:15-11:15 am	Grounds walk, observations for shelter
11:15am-12:00 pm	Shelter design activity
12:00-1:00pm	Lunch (provided)
1:00-2:00pm	Design activity wrap-up, present
2:00-2:15pm	Explanation of installation project
2:15-2:30pm	Break
2:30-4:00pm	Build and install privacy wall (installation project)
4:00-4:30pm	Closing Circle
4:30-5:00pm	Clean up
5:00-7:00pm	Community Dinner (optional, potluck)

During a typical class session, students first learned about the theory behind a permaculture element, observed a working example of that element, then engaged in a design activity. In design activities, students were provided with a set of requirements and tasked to produce a design featuring the permaculture element of topic (e.g., food forest, shelter, water harvesting). Design activities typically featured one element. In both communities, students participated in situated activities to understand how some of the elements of a permaculture design are implemented. The implementation tasks were typically short, around 1-2 hours, but often large projects, taking advantage of the extra-man power provided by eager students to learn.

Occasionally, PDCs in both communities took students to offsite permaculture locations. At the offsite locations, students encountered the same structures for learning as they did at the community education centers. For example, students learned about greywater at a site where other greywater techniques were in place (Live Oak PDC-2012), learned how to design sustainable polycultures at a site where many polycultures were thriving (Manzanita PDC-2014), and learned how to install an annual garden at the house of a client (Manzanita PDC-2014). For most off-site class days, students engaged in each of the three kinds of learning experiences (lecture theory, practice design activity, situated installation).

For both communities, the final design project was a situated learning experience, in which small groups of students created a design for a client with only a brief consultation with the instructor. Clients included private community gardens, public community gardens, schools, homeowners, commercial property owners, and farms. Students went to the site location to do an analysis of the site and to interview the client. Then the groups met to create a design for the site. Groups presented their designs to the class on the final day of the PDCs. In both communities, students engaged in this process concurrent to learning new theory, design techniques, and installation practices. This task was challenging for all students involved as it revealed how much they still needed to learn to engage in the practice as full participants.

The primary Live Oak PDC instructor offered students reduced fees for the PDC if they also engaged in short-term apprenticeships. The apprenticeship required students to implement and maintain permaculture elements at the instructor's local farm and aid the instructor in permaculture design for her commissioned jobs for four hours per week.

Newcomers expected that a short-term course would be sufficient for learning how to design and install agroecosystems, but the closing discussion for each PDC revealed that students felt they were far from obtaining the required skills. During informal follow-up discussions with participants and course instructors, many students said they were still interested in agroecosystems, but did not maintain an involvement in designing, building, or maintaining agroecosystems, meaning they did not continue to engage in legitimate peripheral participation.

3.2. Methodology

The following chapters are based on observant participation of permaculture factions in these two grassroots sustainability communities and on action research with those communities to build a plant database. Anthropologist João H. Costa Vargas differentiates the term *observant participation* from the traditional *participant observation* to underline the importance of participation rather than observation. He says, "[the] observation becomes an appendage of the main activity" (Vargas 2008).

Activist research requires dialogue and collective work with activists prior to finalizing research questions and research objectives (Hale 2001). During these field studies, I was an activist first and researcher second. I engaged the communities with an activist agenda and supported participants beyond the research, for example, by managing a community website. I argue this stance was important in building trust, fostering a long-term commitment and responsibility to both the community and the research, and helping me form an insider perspective and gain a deeper understanding of each other's goals. Martínez (2008, 204) argued that "Activist research, to a greater degree than other research models, depends upon the establishment of a relationship of trust between the researcher and the activists." Thus, I felt it was necessary to build trust before community members would feel comfortable enough to engage as participants. After building personal relationships, participants were open to engaging in audio-recorded interviews, surveys, and photographs of artifacts. My personal relationships allowed me to engage in spontaneous conversations about my research and gain their opinions of being research participants. Newcomers to the communities also needed to feel accepted by their community before participating in community activities, including research (Organ and Ryan 1995). Many newcomers to the Manzanita permaculture community were unwilling to engage in data collection activities, especially interviews, until they made personal connections with the existing community and especially with me, the researcher.

Table 5 Research method mapped out by phase and community

Method/ Research Phase	1 Live Oak	2 Live Oak	3 Manzanita	4 Manzanita
Observations	x	x	x	x
Design Workshops	x			x
Survey of Practitioners		x		
Interviews			x	
Artifact Collection	x	x	x	x
Referenced Resources	x	x	x	x

My findings emerged from six forms of qualitative methods, though not all six methods were used in all four phases (see Table 5). As I continued my education, I was able to refine my methods and gather more precise data from the Manzanita community. The methodological triangulation of these inquiries led to compelling themes for information challenges and the requirements for the SAGE Plant Database.

3.2.1. Observations

The first method entailed observing both communities as I participated in different roles, including student, facilitator, and volunteer. I recorded my observations by writing notes while participating in PDCs, workshops, and other community events. My early notes were predominately taken from a student perspective. As my research began to take a more defined shape, my participation notes included research-based observations as well. For example, as a student my notes focused on the permaculture concepts I was currently learning, but when I became a facilitator, my notes also reflected how participants engaged with the concepts they learned. At the end of each activity with the Manzanita community I intentionally wrote “thick descriptions” (Geertz 1994) of the day’s events, taking care to provide cultural context and critical thoughts for my observations. A thick description not only describes the observed behavior, but also the context of that behavior including explanations and meanings defined by the participants engaging in the behavior (Mills, Durepos, and Wiebe 2010).

3.2.2. Design Workshops

In this dissertation, design workshops were used to discuss the design of SAGE and the SAGE database. I gathered community members with the intention of discussing the requirements of the SAGE Plant Database, both in terms of the short-term development requirements and the desired long-term impacts on the community and grassroots sustainable agriculture at large.

Creating a Common Design Future. I invited the participants of the Manzanita Community to participate in an "Creating a Common Design Future" action-research workshop at the UCI Arboretum in 2015. The goal of this workshop was to understand the community's shared common design future to the degree that they have one. Based on DiSalvo's (2009) tactics that supports the design and construction of publics, I designed a workshop that guided community members in the projection of their society in a potential future scenario of their creation and tracing of critical artifacts in the system that are implicated in or effected by the nature of the future scenario. The result of this workshop is shown in the prologue.

In HCI, using fictional futures to explore implications for technology design with speculative design or design fiction is an accepted and valued practice. Tanenbaum et al. (2016, 3) argue that design fictions, typically films about the future, highlight "values and intellectual commitments associated with a new technology." Hauser, Desjardin, and Wakkary (2014) used design fiction to "unlock people's imagination, encourage reflection, and inspire action towards a more sustainable reality" at their university. Dunne and Raby (2013, 102) use speculative designs to "question the meaning of technology itself" in effort increase the opportunity of achieving desirable futures. Baumer et al. (2014, 762) created and curated abstracts for papers that could be published at CHI in 2039 to explore "what will constitute rigorous, publishable research in the future." In this dissertation, the process of constructing a design future allowed participants to critically analyze the long-term values of Manzanita sustainable agriculture community and how those values could and should be supported and represented by information technology.

Permaculture designers create sustainable polycultures that naturally regenerate and support long-term goals – goals with a time horizon of many human generations or longer. Through informal conversations with community members, I learned that environmental and food system sustainability were long-term goals for participants. Most participants believed that societal collapse was imminent or would be imminent if modern societal norms, and in particular consumer behavior, did not change. Most participants said that natural disaster, ecological crisis, and resource depletion were the most imminent threats to society. Many said that financial upheaval had already started and was going to get worse. Participants believed that by engaging in permaculture, they could reduce their and their communities ecological imprint, foster the regeneration of natural resources, and be prepared for a collapse.

Dewey (2012) defines a public as a group of people addressing a common problem, or the indirect effects of a common problem, in the same manner. Just as publics are constructed to address a common problem, they in turn dissolve as the common problem is solved. The participating communities were, in effect, publics using permaculture and agroecosystem techniques to address food security, climate change, and environmental degradation. Sustainable polycultures come into maximum effect decades after they are planted because the public is attempting to address issues both in the present, but also issues they anticipate occurring in the long-term.

Sixteen participants attended the three-hour workshop, which was also audio recorded to enable later transcription. I engaged participants of the Manzanita community in a critical exercise that yielded a distant, desirable design future grounded in their community's values and practices. First, I prompted participants to create a high-level design for a three-acre plot of land in the UCI Arboretum. During this exercise, we highlighted the values embedded in the present system. Then, I asked participants to imagine the environmental, socio-cultural, technological, and economic future of the surrounding metropolitan area in 30 and 70 years, and how that would impact their modern agroecosystem design process.

In each future scenario exercise, we first individually noted the natural environment, the social community, our personal lives (or the life of a younger loved-one), the role of technology in creating agroecosystems, and a brief justification for the scenario. Next, we shared and discussed each of these scenarios. The audio was transcribed in the week following the workshop. This method was demonstrated at the 2018 Workshop on Longer-term Design Thinking at the University of Washington in Seattle (Friedman, Odom, and Yoo 2018).

I presented the resulting 30-year design future in the Prologue of this dissertation. All data for the 30-year design future came from the "Creating a Shared Design Future" workshop. I coded and categorized the data to understand the long-term values and visions regarding technology, agriculture, environment, and social structure. I utilized the emerging themes regarding long-term technology, agriculture, environment, and social values and visions to guide the formation of a shared likely future scenario and to iterate on the concept of a suite of sociotechnical systems for the community. In addition to transcribing the audio, I referred back to the individual participant's hand-written worksheets for clarification of points made in the group conversation. In theory, one shared desirable scenario could also be created if the group felt the likely scenario was distinct from a desirable one. After completing this process, I shared my synthesis of the design future with the participants inviting feedback and changes, and two participants made edits or otherwise provided clarifications.

The 30-year future represents a meta-goal of the community, as an information ecology, and could be used when community members, and especially consultant technology designers, create new or evolve old systems.

The group was less-aligned in their vision of the 70-year future and was not able to establish a shared vision in the allotted time. Such an outcome demonstrated that there were significant individual differences for the group to create a shared long(er)-term vision. Both kinds of outcomes are valuable when considering long(er)-term design.

Plant Database Design Workshop. After the conclusion of Live Oak PDC-2011, I met with three of the educators to discuss requirements for a plant database. This design workshop lasted two hours. I did not bring pre-defined questions, early designs, nor preconceptions of what domain knowledge the database should contain. I brought my computer science training for how to design and construct databases. The educators primarily guided the direction of the conversation. I made extensive notes during the conversation, primarily engaging in the conversation by asking for clarifications and offering technical explanations. Occasionally, however, I offered suggestions for requirements that seemed appropriate but had not been discussed.

The educators were motivated by their pupils' requests for a database and described the requirements they thought the database needed. Additionally, they emphasized that a plant database is relevant to established practitioners. Specifically, they viewed the plant database as an opportunity to facilitate the formation of expertise but also offload the individual's responsibility to remember or document plant information.

3.2.3. Survey of Practitioners

In October 2012, I distributed an exploratory open-ended survey to the Live Oak permaculture community. Fourteen members of the community who had been active for at least one year responded to the survey. The survey asked participants about their use of technology, digital and otherwise, in the design of sustainable polycultures. I confirmed that many participants desired a plant database for their local community. Participants also provided useful information regarding what would make a plant database useful to their design process. The survey questions were:

- What permaculture systems do you design?
- What are the primary components of the design?
- Briefly describe your design process.
- What technologies and tools do you use in your design process?
- Do you typically design for clients, yourself, or both?
- If you design for clients, how do you determine their needs?
- How do you determine the arrangement of the plants in your design?
- If plants are a critical part of the permaculture system you design, what attributes do you use to determine which plants to use in your design?
- Please describe why you use the aforementioned digital and computing technologies help you complete your tasks?
- What doesn't work well with the technologies you use in your design process?
- What technologies do you wish were available to help your design process?
- What design methods do you utilize, and why?

3.2.4. Interviews

I conducted 30-minute to one-hour semi-structured interviews with five newcomer participants of the Manzanita community. All of the interviewees were in their first year of participating in the community. I conducted these interviews to gain additional insight to their learning experience, how information technology affected their learning process, and how they used information technology in their design projects. I conducted these interviews during breaks or after educational sessions in Manzanita PDC-2014. I audio recorded all interviews and transcribed the recordings within one week of the interview.

3.2.5. Community-Generated Artifacts

Community generated plant list and plant information sheet artifacts are of particular relevance to this research. Plant lists specify plants that can be used for a specific purpose, such as trees that provide shade. Plant information sheets are similar to plant lists, except instead of only listing the names, the sheet provides a breadth of information on the species. I analyzed 20 community-authored plants lists and information sheets. Fifteen plant lists were authored by members of the Live Oak community, and five were authored by the Manzanita community. There were at least nine authors of these 20 artifacts, many contributing to multiple plant lists, and some partnering to create an artifact.

Ten of the plant lists and information sheets were created by community educators and distributed to students in PDCs. These plant lists and information sheets were among the materials included in a student's PDC journal. Most of the artifacts included in PDC journals were provided by educators, but PDC journals also included the students' personal notes.

Community members created the other ten plant list artifacts for events independent of the PDC. For example, a participant created artifacts for a special seminar that introduced the concept of building a hugelkultur (see Figure 1-5)– an alternative to a raised bed (Holzer and Whitefield 2011, 40).

3.2.6. Community-Referenced Resources

During their agroecosystem design process, community members referenced plant lists and information sheets in texts and online resources. I witnessed, in detail, participants using nine published texts in their agroecosystem design process (see Table 6). I then analyzed these nine texts. I did not include other community-referenced books in my data analysis because I did not observe them being used by the permaculture community members for extended periods of time. In addition, I analyzed four online resources used by the community (see Table 7). These four online resources were primary resources in participants' search for plant information. Participants deliberately visited these sites and searched plant information using their interface. This kind of interaction suggests participants found sustained and significant value in the plant information resource.

Table 6 Texts referenced by participating communities

Community-Referenced Texts

Title	Author
Edible Forest Gardens – Volumes 1 and 2	(Jacke and Toensmeier 2005a, 2005b)
Gaia's garden: A Guide to Home-Scale Permaculture	(Hemenway 2009)
Permaculture: A Designer's Manual	(Mollison 1988)
Perennial Vegetables: From Artichoke to Zuiki Taro, a Gardener's Guide to Over 100 Delicious, Easy-to-grow Edibles	(Toensmeier 2007)
Rainwater Harvesting for Drylands and Beyond – Volumes 1 and 2	(Lancaster 2013, 2007)
The New Create an Oasis with Grey Water	(Ludwig 2015)
How to grow more vegetables (and fruits, nuts, berries, grains, and other crops) than you ever thought possible on less land than you can imagine	(Jeavons 2012)
Integrated Forest Gardening	(Weiseman, Halsey, and Ruddock 2014)
California Native Plants for the Garden	(Bornstein, Fross, and O'Brien 2005)

Table 7 Community-referenced online resources about plants

Community-Referenced Online Plant Information Resources

Online Resource	Reference
Electronic Data Information Source (EDIS) from the University of Florida Institute of Food and Agricultural Sciences Extension	(UF/IFAS Extension 2018)
USDA Plant List and Accepted Nomenclature, Taxonomy, and Symbols (PLANTS) Database	(USDA and NRCS 2018)
CalFlora: Information on California plants for education, research and conservation	(Calflora 2014)
Tree of Life Nursery Plant Profiles	(Tree of Life Nursery 2018)

I did not analyze community-referenced online resources that users made single-page visits to through a search engine, such as Google. Even though participants accessed some websites multiple times through search engine queries, they did not (typically) use the websites' interfaces to search for material. The low visit-counts and search engine-mediated visits indicated that users did not find those sites to have significant or sustained value relative to the four websites I analyzed.

3.2.7. Data Analysis

I analyzed the data and artifacts using established coding and categorizing techniques for qualitative data (Lofland et al. 2006; Saldaña 2013). Saldaña characterizes coding as deciphering what an artifact or passage of data means and then encoding that meaning with a label (Saldaña 2013, 4). Coding is largely an "interpretive act" (Saldaña 2013) and allowed me to gain a first impression of the data.

For anonymity, all names in the data have been replaced by pseudonyms or blacked out from images. All mention of names in field notes and transcriptions were de-identified using an online name generator.

Details of the data analyses for identifying information challenges that participants faced, the communities' values in technology, resistance against "business as usual," and the long-term future, and the associated findings, are presented in Chapter 4. The data analysis for the SAGE Plant Database design requirements and the associated findings, are presented in Chapter 5.

CHAPTER 4:

Permaculture Field Studies

This research began as an exploratory field study of permaculture factions in two grassroots sustainability communities. Through this process, I came to understand the technological and societal values, long-term design contexts, and information challenges of these groups. “Technology values” denotes the ways participants felt about and used technology. “Resistance values” denotes the ways participants worked to change their community’s standing in society. “Long-term design contexts” denotes the anticipated future the community is designing for and what they hope to achieve in that future. “Information challenges” denotes the information-based barriers to legitimate permaculture practice, as experienced by participants. These findings are presented in this chapter.

4.1. Information Challenges

I analyzed observations, surveys, interviews, and artifacts using established coding and categorizing techniques for qualitative data (Lofland et al. 2006, Saldaña 2012). After I identified patterns of information challenges, I engaged in a cycle of coding and categorizing in an effort to understand the extent and nature of such challenges by writing “thick descriptions” of prominent examples (Geertz 1994). These “thick descriptions” are the basis for the information challenges presented in the following chapter. I present the information challenges in context of the permaculture process. I discovered four primary categories of information challenges that newcomers to permaculture communities face:

(1) difficulty determining what information should come from the client
(2) lack of site-specific environmental data
(3) difficulty organizing and visualizing complex relationships among design elements and between design elements and the surrounding environment
(4) lack of region-specific plant lists

The information challenges represent those that made it difficult for Live Oak PDC-2011, Live Oak PDC-2012 and Manzanita PDC-2014 participants to practice permaculture (i.e., engaging in the design process and implementation). I only featured those challenges that occurred in many contexts and for many students. In some cases, students made short cuts or did not engage completely and thoroughly with the design process, but for some these challenges prevented them from practicing some portion of permaculture all together (e.g., creating implementable designs).

4.1.1. Which Information Should Come from the Client

Gathering and synthesizing data are the primary tasks in the first two steps of the permaculture design process – needs and site analysis. There are three resources from which this information can be collected: client, designer (i.e., oneself), or online. Information from the client is mostly to help establish a vision for the site in the need's analysis, but the client may also have information pertinent to the site analysis. The designer will derive much information about the site by simply looking at the site during the observation process, but precise information usually requires some form of measurement, such as elevation change. Online datasets are valuable resources for site analysis information because they contain data that otherwise requires expensive equipment or a refined skillset to accurately collect. Unfortunately, these data are typically available for a scale larger than the site (e.g., weather data would be from the nearest neighborhood weather station rather than from the site).

Although a wealth of information resources exists, participants had difficulty determining what data should come from which resources. The most notable mistake students made was to offload the task of acquiring data onto the client. For example, Pauline, a landscape designer, suggested that one of the most pressing issues to ask a client is, "where does the sun fall?" However, a client may not be fully aware of the sun patterns on their property. Terrance, the instructor of Manzanita PDC-2014 explained, that a person can use a compass to "calculate the trajectory of the sun to know where it is going to arc and determine how the plants will be exposed to the sunlight." There are also online tools to gather observable information that might be hard to deduce in a short visit like, for example, climate data. Terrance described which details needed to come from the client: "From observation we know where the sun is, we know what the soil is like, we know what is growing, but what we don't know is what [the client] wants."

Because newcomers do not have refined experience in observation, creating site surveys, and generating designs from client requirements, they are inclined to ask clients for any information they might need to create a design, like environmental data or even design decisions (e.g., does the client want a keyhole garden or a raised bed garden).

However, a client's time is valuable, so it is essential for the designer to use the client's time to determine the client's vision and other information that is not available from other information resources. Without knowing which data must be obtained from the client, which data should not be collected from the client, which data are available from other resources, and which data should be collected manually, a newcomer will face a multitude of challenges such as running out of time, failing to clarify the client vision, failing to collect other pertinent data from the client, or forcing the client into making decisions about design elements they do not understand.

4.1.2. Site-Specific Environmental Data

Gathering environmental data is the primary task of the site analysis step in the permaculture design process. In theory, all environmental information needed to engage in the design process can be gathered via passive and active observation and spending long enough periods of time on the site – sometimes over a year to observe all seasons (Mollison 1988). However, most designs are finished in days or weeks, in which case environmental information is inferred from observations in a single visit and gathered from online resources. Because design projects in each PDC were completed over the course of 4 to 6 weeks, online resources for environmental information were used in the site analysis of each design project.

Although the online resources were valuable, students found that much data were not available online at all or at the level of detail they needed. Wendy and Spencer from

Live Oak found it difficult to gather environmental data of their design site for their term project. Prior to when I joined Wendy and Spencer at their site, Wendy had taken it upon herself to start the sector analysis (Figure 4-1), with data that she gathered from online resources. For example, she used wind pattern data collected by the municipal airport across the highway from the school and used historical temperature and rainfall data from a weather website. Although the USGS Web Soil Survey provided basic soil make-up and topography data for the area, Wendy determined the data was not at a resolution high enough to serve their purposes. For this reason, Spencer constructed a rudimentary A-frame level to find contours at high and low points on the site (Figure 4-1, in light brown). It took more than three hours to map the topography of their roughly 3,000 square feet site. Wendy and Spencer took soil samples and send them to an agricultural extension office at the regional university for a free analysis. However, they did not get back results before the project had ended. Similarly, because their time to complete the project was only five weeks, they had to estimate seasonal sun exposure and could not confirm if the wind data collected from the airport was accurate on their property.

This example demonstrates how online resources often contain data of a fidelity lower than the agroecosystem design requires. Gathering these data is time consuming, the tools and access to services can be costly (e.g., processing the soil), and collection methods require a range of training or practice (e.g., using surveying equipment for accurate topographic measurements). Each of these factors can prevent newcomers from acquiring data necessary to create a functional design.

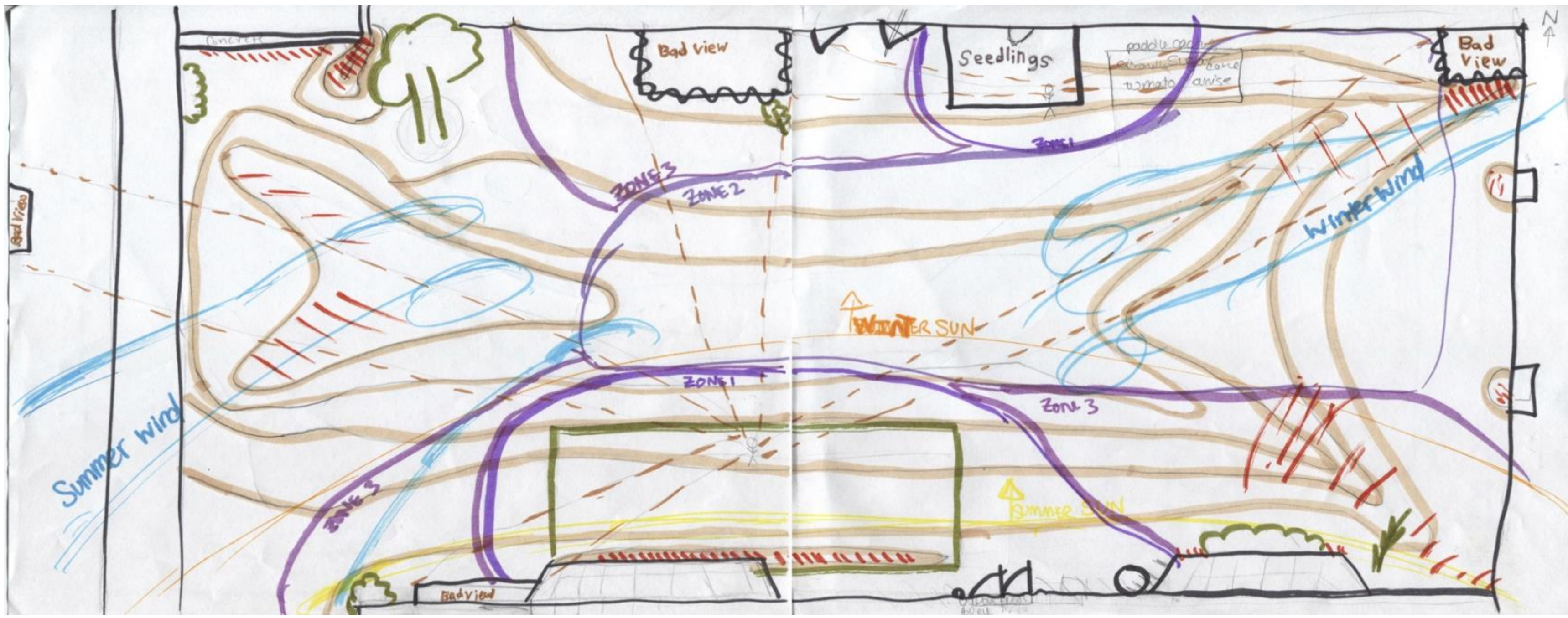


Figure 4-1 Sector analysis of an elementary school garden. In the figure, black represents existing structures (e.g., concrete pathway edges, buildings, doors, etc.), brown represents topography, red represents erosion, purple is outlining zones of activity, blue represents the prevailing summer and winter winds, yellow is the boundary for the summer sun, and orange is the boundary of the winter sun. Used with permission by participant group.

4.1.3. Region-Specific Plant Information

I collaborated with participants in Live Oak PDC-2012 for my very first experience in designing a sustainable polyculture. During this in-class assignment we referenced several books and plant lists, such as (Hemenway 2009; Holmgren 2002). We found it impossible to complete a functional analysis for each plant in the polyculture because it was a time-consuming task. Nor could we find essential information, such as the flood tolerance of most plants, which is important because flooding was common during the wet season. When presenting our best effort at creating a polyculture, we learned that the tree we had chosen as our key species, the Florida Soapberry (*Sapindus saponaria*), did not grow in the environment we were designing for (i.e., it grew in Florida but in a different climate zone).

The students of Manzanita PDC-2014 also struggled with designing sustainable polycultures. One student described her experience of performing functional analyses on plants for her polyculture: “It was like I had fallen into the pit of Google, going in circles only to come out hours later having forgotten what it was I was initially searching for.”

Most students did not have the requisite plant knowledge to determine which plants were suitable for the environment. For some students, the need to be precise in their choices caused them to spend a tremendous amount of time searching for information on a single plant across multiple resources. The little information for their region that did exist was distributed across many information resources. Further, some of the information was from sources of questionable integrity, such as blog posts, and more qualified resources were not well-known or easy to find. Because sustainable polycultures were commonly a component of participants' permaculture designs, the unavailability, division, and questionable integrity of this information was a barrier to practicing permaculture. This barrier is a driving factor behind the concept of SAGE.

4.1.4. Organizing and Visualizing Complex Relationships

Creating functional designs, whether broad-scale or implementable, were the primary activities for both PDCs. In the case of the broad-scale design (Figure 4-2), the purpose for the garden was two-fold: a place where athletes practicing on nearby fields could rest, and an outdoor environment to support educational initiatives. In the case of the implementable design (Figure 4-3), a student designed a fruit tree polyculture around a client's house on photocopies of a hand-drawn base map. On her first pass (left), the student lists trees that could create a robust polyculture and meet the client's vision. She uses different kinds of writing tools to make modifications visible. On her second pass (right), the student makes final design decisions using different writing utensils for improved readability of details.

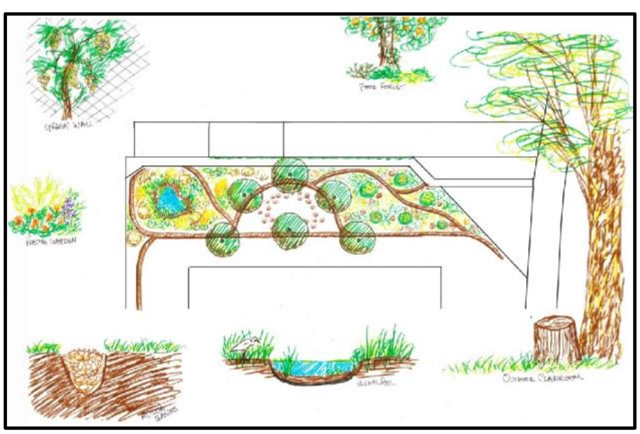


Figure 4-2 Broad-scale design of a high school garden. Used with permission by participant group.

Students used a range of design tools to engage in functional design. There is a significant amount of information that

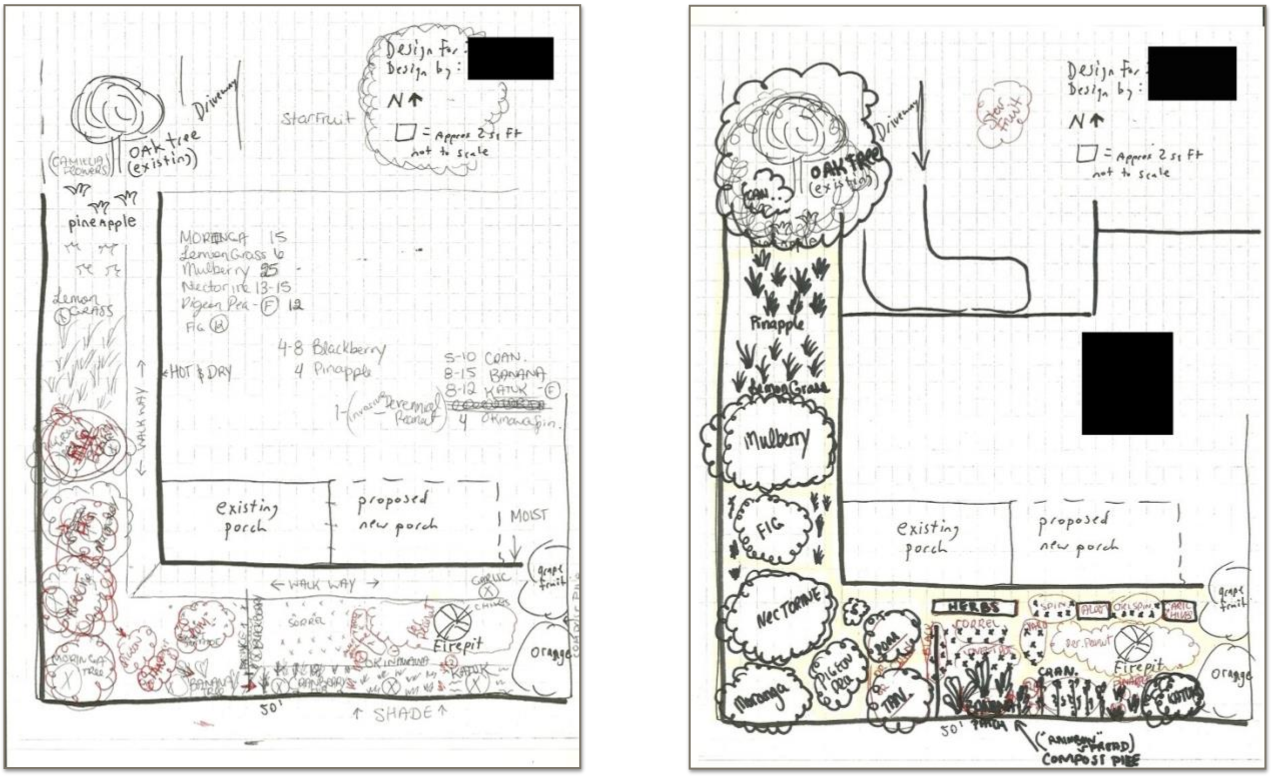


Figure 4-3 Implementable sustainable polyculture design for a client. Used with permission by participant.

a designer must organize to create a functional design. Some of that information is unknown, and, especially when working with more than five or so elements, there is too much information to keep in mind at once. Permaculture practitioners have adopted design tools and methods to cope with the information overload.

The tools instructors introduced to the students were predominately used to explore and establish the spatial component of the functional designs. Paper-and-pencil (or other similar writing tools) were used for in-class design activities for both PDCs. During the class activities, the paper-and-pencil medium was used in the following two methods. The first method was to design on a sheet of trace paper that overlaid the base map (Figure 4-4). In this figure, a group works together to map the water run-off of the roof of a single-family home and determine catchment points (bottom right). The water-catchment layer was created with a trace paper overlay for the base map (left, partially occluded). The second method was to design directly on photocopies of the original base map (Figure 4-3). Both methods allowed for iteration. In both methods, the foundation of the design is the base map.


Figure 4-4 Single-family home water catchment and polyculture design.

Students engaged with various other technologies for their final design projects. The most common technique was to use a combination of paper and photo-editing software that allows for visualization of the vertical vegetation and infrastructure layers (Figure 4-2). However, most designs depicted the spatial design from a single axis, typically top down, and without depictions from other angles, spatial design of the vertical layers (Figure 1-2) was under-explored.

The designs had other points of weakness. For example, they omitted important plants that aid in pest control by attracting predatory insects. Students did not have tools to help them visualize and organize the non-spatial relationships among the elements of their designs, whether defined broadly (e.g., edible trees) or at implementable detail (e.g., mulberry, fig, *Moringa*, etc.). Implementable designs require specification of each element of the design and where the elements are placed. Most of the design tools required re-drawing or other time-consuming tasks when experimenting with the placement of design elements. For example, participants that utilized paper and pencil had to re-drew entire designs, often on a layer of trace paper over a static background, to change or experiment with the placement of plants. Without being able to represent all the relationships among the design elements, experimenting with placement was an exercise in attempting to analyze and optimize the observable (e.g., Plant X provides shade for Plant Y) and non-observable relationships (e.g., Plant A provides nitrogen for Plant B).

Students also did not have tools to help them visualize the relationships between elements in the design and other environmental factors. In fact, the process of managing the functional relationships among the design elements was difficult enough that students tried to limit the problem's complexity by only considering on-site environmental conditions and ignoring the neighboring plants and conditions. Depending on the severity of the oversight caused by insufficient tools for organizing and visualizing these complex relationships, the resulting points of weakness could mean the installations will not thrive or otherwise function properly (e.g., cause flooding).

4.1.5. Discussion

This exploratory field study revealed the practices and values of two permaculture communities, showed the importance of information to agroecosystem design, and uncovered four information challenges that served as barriers for newcomers to practice permaculture: To review, the information challenges are:

(1) difficulty determining what information should come from the client
(2) lack of site-specific environmental data
(3) difficulty organizing and visualizing complex relationships among design elements and between design elements and the surrounding environment
(4) lack of region-specific plant lists

The four categories of information challenges are underscored by limited access to expert knowledge, physical and digital tools and processes, and time. Limited access to resources is not uncommon for newcomers to permaculture. In a 2014 survey of permaculture participants across the world, Ferguson and Lovell (2015b) showed that limited access to resources, including economic, natural, technological, social, and temporal resources, constrains full participation in permaculture practices.

Together, these four information challenges prevent students of non-professional agroecology and permaculture from transitioning into practitioners. Without information, participants used considerable amounts of time trying to obtain the missing information by searching for it or creating it. Ferguson and Lovell (2015) reported that constraints surrounding poor access to resources, including time, created feelings of powerlessness which often accompanies marginalization.

These information challenges are amenable to sociotechnical intervention. Raghavan et al. (2016, 428–29) argue for a new domain of sociotechnical systems that provide the detailed knowledge that “agroecological practitioners must have at their fingertips;” facilitate the translation of such knowledge “into functional agroecological systems within specific contexts;” make the scientific knowledge available to those outside of the scientific community; coalesce valuable traditional and informal knowledge that is presently "scattered, inconsistent, uncontextualized, and non-systematic;" and facilitate the application of agroecology techniques to "many thousands of ecologically-unique sites of food production."

I argue that collaboration with HCI researchers is especially import for permaculture communities, like the ones that participated in this research, because it can help actualize an otherwise unsupported potential resource of local agricultural sustainability. Computation is uniquely well suited for addressing a range of information problems in agriculture domains (*Computing Research for Sustainability* 2012), and HCI can help blend together the human and informational challenges these researchers and practitioners face.

In particular, this research addresses a major information challenge – *Lack of Region-Specific Plant Information* – with socio-technological interventions. The lack of plant information is foundational to other barriers to participation in agroecosystem design. Without a comprehensive information source about local plants and their relationships, participants did not have the foundational information needed to start addressing the challenges of agroecosystem design.

The goal of the remainder of this research was to provide community members with the plant information necessary to thoroughly engage with sustainable polyculture design. A resource of such plant information alleviates newcomers' information-based barriers to entry, providing them with greater opportunity to become practicing members of the community. The next section introduces the values of the community that inform the context in which the plant information is or perhaps should be used, organized, and stored.

4.2. Values

> *To propose to blend such a farm with human values is simply to acknowledge that it has no human values, that human values have been removed from it... If human values are removed from [farm] production, how can they be preserved in consumption?*
>
> \- *Wendell Berry (1996, 79)*

In the context of this research, a "value" is something that a person or a community thinks is important. I use this broad definition in effort to also capture both the concepts of ethics and principles because participants often used these three terms synonymously.

In Chapter 2 I highlighted the permaculture ethics and design principles (see Table 8). The permaculture values serve as the philosophical underpinnings of permaculture practice. Here I discuss three other value sets that emerged from these communities – resistance, technology, and long-term values. The resistance and technology values were emergent in these communities, but not explicitly stated in the permaculture literature nor instruction. I engaged in a new cycle of coding and categorizing of observations, workshop data, surveys, interviews, and artifacts in effort to understand the extent and nature of such values. I also facilitated the "Creating a Common Design Future Workshop" to understand the nature of these values in the long-term.

Table 8 Summary of Values

Category	Values
Core Permaculture Values (Holmgren 2002)	- Earth Care – Rebuild natural capital - People Care – Look after self, kin, and community - Fair Share – Set limits to consumption and redistribute surplus
Resistance Values	- Quotidian Insubordination - Engage in typically anonymous, every day forms of resistance, even if illegal, against consumerism and industrial agriculture. - Empowerment - Appeal for institutional change to obtain rights to engage in agriculture and reduce risk of environmental contamination and health complications.
Technology Values	- Selective use – Use ITs to streamline design and management of agroecosystems but set limits to use to minimize detrimental effects on the environment and social fabric. - Modularity and multiplicity - Stack functions of resources, so hardware and information systems can be used for many purposes. - Longevity - Extend life line of IT resources – maintain systems, exchange out components instead of buying new devices.
Long-term Values	- Food sovereignty – access to food and opportunity to grow food. - Regeneration – breakdown, evolution, and growing anew applied to community, renewable and non-renewable natural resources, and infrastructure. - Sociocultural equality and equity – equal opportunity to participate in the formation, possession of, or access to sociocultural capital, knowledge, critical resources, nature, infrastructure, and traditions.

4.2.1. Resistance values

Engaging in permaculture can be a subversive act. It is an explicit attempt to undermine, at the very least, the current industrial food and agriculture system. Instead of the regulated, efficiency-focused nature of modern agricultural institutions, participants work towards independence, self-reliance, personal-value-respecting food and agricultural production. Participants engaged in two forms of resistance – quotidian insubordination and appeals for institutional change.

4.2.1.1. Quotidian Insubordination

Political scientist and anthropologist James Scott describes everyday forms of resistance, or "quotidian insubordination," as relatively low risk, anonymous, and obscure (J. C. Scott 2014). Quotidian insubordination, Scott says (2014, 12), "flies under the archival radar, waves no banners, writes not manifestos."

The most common acts of quotidian insubordination by the participants had an anti-consumerist overtone, such as buying second hand or used materials, not buying or using single use goods like plastics, trading goods or services instead of using money. The most stated forms of quotidian insubordination by the participants included ripping up grassy front yards to plant gardens, collecting rain water, raising backyard chickens, and guerilla gardening. The more outspoken participants suggested that they engaged in these acts in peaceful protest to industrial and governmental infrastructures that regulate their daily lives.

An individual that grows their food, collects their rain water, and prioritizes second-hand traded over new purchased goods is resisting the controlling infrastructures by not participating in them. When this behavior is socially accepted among those engaging in permaculture or other sustainability communities, and neighbors are complicit because they do not report the unlawful behavior, it begins to function as an unorganized form of collective action.

Guerilla gardening was arguably the most subversive occurrence of the communities' acts of quotidian insubordination. A small subset of participants in the Live Oak community met on a weekly or biweekly basis and plant seeds and young plants in typically fallow areas on both private and public property. Although this was an illegal act, the guerilla gardeners believed that leaving the land fallow was more problematic then trespassing or hijacking the space for their own social agenda. The guerilla gardeners gathered just after sunset, each bringing seeds or plants from their personal store and basic hand tools. They typically rode bikes to their target locations and wore dark clothing in effort to be inconspicuous.

When I asked the guerilla gardeners how they anticipated the plants would grow and the food would get harvested, they explained that a successful harvest was secondary to making a social statement. Many of the plants would not grow well enough to produce a bountiful harvest because the plants are unmanaged -they do not have consistent irrigation, only rainfall, nor are growing in properly amended soil. Also, some of the sites were fenced, and most citizens are unlikely to trespass beyond a fence for fruits and vegetables of questionable origin. Instead, it was their goal that someone would *notice* that food was growing in once vacant, fallow space, that the local society would learn that food could grow in unusual places in an urban and suburban environment, and that the local government would notice that its citizens want more local, sustainable food production. However, when collective action creates a noticeable effect, government and industry retaliates and explicit resistance is born (J. C. Scott 2014).

4.2.1.2. Appeals for Institutional Change

Unlike the acts of quotidian insubordination, appeals for institutional change were not anonymous and were meant to be noticed. For example, the Live Oak sustainable agriculture community appealed to the local government regarding the right to grow food in front yards. This began when a gardener in Live Oak was cited by the city for not having appropriate ground cover in his front yard as instead of grass, he had a garden (Schlueb 2013). This and similar events motivated individuals to lobby for new and changed city ordinances, run for local office, or run for their HOA board in order to change the institutions they were living within. On several fronts, the Live Oak sustainable agriculture community was successful. For example, in the last five years several counties in Live Oak have started programs to help people raise chickens in their suburban back yards (Hudak and Weiner 2017).

I witnessed similar forms of striving for institutional change by the Manzanita community. One participant petitioned against the use of pesticides on school grounds from her children's district to the state (Shine 2015). As more community members began installing gardens in their children's schools, the movement to ban pesticides on school grounds became a community effort. Although the group's effort was unsuccessful, the community's awareness surrounding the issue has increased.

4.2.2. Technology values

Participants used ITs in their practice to address problems of sustainability, particularly in the context of agriculture. Participants depended upon ITs in three contexts: (1) design of (typically agricultural) infrastructure, (2) coordinating design projects and community events, and (3) independent learning. Participants used ITs during the permaculture design process. Participants used publicly available information on the Internet (e.g., Google satellite maps, USGS topographic and soil maps, climate and weather databases, and historical land ownership government websites) to create maps and profiles for design sites. They used online plant databases for determining the flora components of a design. Some participants used 2D and 3D drawing software (e.g., Adobe Photoshop and SketchUp) to refine their designs. Participants also used word processors and spreadsheet applications for office and business management.

Participants found that ITs improved their work by helping them accomplish tasks faster, more accurately, and at lower cost. One student in the Manzanita PDC explained how he was able to reduce the time needed to accomplish a task using IT: "We are able to get a great understanding of weather over a year without observing for that long." Another explained how ITs provided them with data essential to the design process:

"Satellite images provide accurate top-down perspectives of the site and surrounding area that we wouldn't otherwise have."

Participants used email, phone, text messaging, and instant messaging to coordinate with others. One participant used Survey Monkey (a survey website) to distribute client needs surveys. Several participants used Doodle polls and chat features in Google Docs to coordinate with peers or clients. Participants used Facebook, Meetup, and email to coordinate and share information at the community level. The Live Oak community had a periodic email newsletter and website for announcements and shared event information.

Although participants used ITs to address challenges of sustainability, they had two philosophical misgivings in doing so: (1) negative environmental impacts of IT manufacture, use, and disposal; and (2) distraction from physical human and environment interaction. These misgivings are not, however, unique to these permaculture communities. ITs are known by HCI researchers to be implicated in the problems of sustainability (Baumer and Silberman 2011; DiSalvo, Sengers, and Brynjarsdóttir 2010; Tomlinson et al. 2015) and social isolation (Ahn and Shin 2013; Rosen, Carrier, and Cheever 2013).

In accordance with the extended values of the permaculture movement, participants preferred utilizing renewable and local resources to non-renewable or distant resources (Holmgren 2002). However, non-renewable resources, often from distant places, make up and power IT. This misgiving can explain some of the intentional non-use of ITs that I observed. Some participants utilized and repaired old laptops and mobile devices with the intent of keeping the technology until it stopped working. Others focused on reducing operational energy from non-renewable resources. For example, one participant kept his phone powered off until he needed to make a phone call or was ready to check for messages. Many other participants in the Live Oak community owned small solar cells that they used to charge their small electronic devices, such as cell phones.

The second misgiving arises from the neglect of social interaction with people and other living things in the physical environment when using ITs. The extended values of the permaculture movement call for a "culture of place" that connects people to each other, the land, and nature (Holmgren 2013). Participants believed that face-to-face social interaction is more effective for forming community than IT-mediated interaction because ITs pull attention away from the physical environment including people and nature. Thus, participants engaged in selective use of technology, a form of technological non-use as described by Baumer et al. (2015). Participants believed that reducing or eliminating their use of ITs for a period of time allowed them to value social connections. For example, one participant described his decision to use a basic phone rather than a smart phone in order to avoid distractions and improve his in-person interactions:

> I used to have a smart phone, but I got rid of it. I was at the student union one day and realized that everybody was looking at their smart phone or listening to music with headphones instead of getting to know each other. I feel like that happens everywhere. I didn't like that I was missing out on what was happening around me or that I sometimes found what was happening on my phone to be more important than what somebody was saying to me. I like the interaction I have with

people better now. I often leave my phone somewhere and don't think about it for hours. It's refreshing.

4.2.3. Long-term Values

The issues addressed by these communities – climate change, resource scarcity, societal limitations, and food security – are considered multi-lifespan problems. When exploring how to address these multi-lifespan problems, the community demonstrated three values: food sovereignty, regenerative design, and sociocultural equality.

Food sovereignty for this community may be better described as critical resource sovereignty because the objective of permaculture is to obtain and managing all critical resources, also including energy and water, for sustainable human settlements (Mollison 1988). Altieri's explanation of food sovereignty reflects the nature of these communities' values of food sovereignty – food sovereignty emphasizes "farmers' access to land, seeds, and water while focusing on local autonomy, local markets, local production-consumption cycles, energy and technological sovereignty, and farmer-to-farmer networks" (Altieri 2009, 104). With long-term personal water collection and recycling features, and solar energy utilization, both by strategically taking advantage of the sun's path and by using solar cells, participants aim to achieve long-term local, and even personal, autonomy of critical resources. Specifically, the communities' long-term food sovereignty values encourage the formation of an agrarian society in place of the industrial society we have now.

Regeneration denotes breakdown, evolution, and growing anew. On the surface, regeneration could counter the "permanent" in permaculture. However, participants did not value permanence in the sense of unchanging. For participants, permanence required the ability for something to change with and adapt to slow, multi-lifetime changes and problems, such as climate change and resource scarcity. Participants applied the value of regeneration to the community itself – evolving its goals and values to global and local changes and fostering the arrival of newcomers and the passing of old-timers. They also applied the value of regeneration to renewable and non-renewable resources – facilitating the regeneration of natural resources, like using earthworks to sink rain and irrigation water into the ground, and chemical exchanges, like amending soil with biochar for carbon sequestration. Furthermore, they applied the value of regeneration to infrastructure – creating agricultural systems that function as ecosystems, like sustainable polycultures, and using waste to create energy, like breaking down organic material in bio-digesters to create biogas. Finally, participants applied the value of regeneration to technology, indicating an interest in hardware components and power sources that could grow and decompose.

Socio-cultural equality, as described by these communities, entails a society of people who have equal opportunity to participate in the formation and possession of sociocultural capital, knowledge, critical resources, infrastructure, and traditions. Achieving equality is contingent upon socio-cultural equity, which entails providing all people with the resources they need to be successful. Broadly, participants view the current industrial society as one that fosters inequality and disenfranchisement. They envision a future sustainable agrarian society that disaggregates and disperses wealth and provides people with the opportunity to have direct engagement with their community and its economy. They believe long-term collective action can transition their communities from the current industrial society to a future sustainable agrarian society.

Although most participants shared these long-term values, they disagreed on the likelihood of future societies representing these values. One participant described these ideals as "probably unrealistic" and "utopian in nature," but never-the-less longed for food sovereignty, regeneration, and equality in society. Another participant challenged that assessment, pointing out that most of the participants had already agreed that some sort of collapse was likely to occur. If society collapses in thirty years, he posited, in every moment up to and through that point, they should be laying the foundation for a more just and sustainable society. In summary, community members shared long-term values but envisioned the future in which they would be practiced and the effect they would have differently.

4.2.4. Discussion

The emergent resistance, technology, and long-term values, though not explicit in permaculture literature or instruction, are influenced by the core and extended permaculture values. Growing food, fighting for rights to grow food, guerilla gardening of vacant spaces, and designing long-term solutions in the form of sustainable polycultures for clients and the community are all motivated by the permaculture value to "look after self, kin, and community." The permaculture value of "rebuilding natural capital" – where natural capital denotes the worlds natural assets such as air, water, geology, soil, and all living things – and "set limits to consumption and redistribute surplus" motivates how participants engage in these activities. For example, in contrast to common annual gardens that quickly degrade soil and utilize chemical fertilizers and pesticides, participants' annual gardens incorporated biointensive methods, such as deep soil preparation, the use of compost, close plant spacing, and synergistic combinations of plants, (Jeavons 2012) with the goal to encourage long-term soil health, reduce resource consumption, and preserve genetic diversity. As an example, the guerilla gardeners' spare seeds and plants were "redistributed" to the community and other living species for food and habitat.

Given the extent to which participants mindfully incorporated the permaculture values into the ways they engage with the world, it is important that the information systems that are designed for them support this intentionality. Very often, designers build information systems that uphold their own self- or organization-serving values and goals, such as popularity by way of mass production of short-lifespan products (followed by e-waste) (Robinson 2009), profit by way of aggregating value from free labor (i.e., heteromation) (Ekbia and Nardi 2017), innovation by way of Earth's natural resources (Schebek et al. 2015), or social change by way of mass adoption (i.e., technology evangelism) (Tsukayama 2017). Sometimes those self-serving values are in conflict with stakeholders' values, and so stakeholder values are set aside. Sometimes technology evangelists create a system that has inherent designer-serving values and then persuade a critical mass of people into adopting that the system, thus implicating them in supporting the designers self-serving values or goals even if potentially at a cost to themselves (Maher 2016).

Many permaculture participants abandoned technologies that were implicated in a social or environmental issue, such as certain brands of smartphones, laptops, and other devices that have rechargeable lithium ion batteries containing coltan and the ecological and human security impacts mining that coltan has had on the Congo (Frankel 2016). Since participants were willing to forgo ubiquitous technologies or technological services because they were in conflict with their values, it is imperative that technologies designed for these communities are in support of, and certainly not in conflict with, their values.

Information systems for this group should support participants' efforts to engage in "people care, earth care, and fair share," but also work to support their resistance, technology, and long-term values. If an IT is designed to support some form of quotidian insubordination, such as producing and trading open-pollination seed and plants, and participants prefer to engage in these acts anonymously, then ITs for this group need to allow for anonymous usage and interaction. Furthermore, that IT is meant to support a community and therefore must be a community asset, not subject to heteromation. Heteromation is the occurrence of a single person or entity financially benefiting from the work of an unpaid or underpaid community (Ekbia and Nardi 2017). Heteromation is directly at odds with the community's anti-consumerism and long-term equality values. The IT needs to be "open" to the community so it can "regenerate" the system to match their evolving needs in the long-term. Also, the IT needs to work across a range of platforms and operating systems, from new to very old, from mobile to desktop, and work even with intermittent internet connectivity.

ITs designed for this group must also fit in with their selective use values. Overwhelmed by "technologies that reach into all corners of life" (Bødker 2015, 26), these communities do not desire yet another complex sociotechnical solution with marginal returns. In modern times, sociotechnical infrastructures are not always well thought out solutions. Bødker (2015) explains that in the third wave of HCI, researchers rapidly designed and introduced ITs in an exploratory fashion, typically with short-lasting or little impact, to understand which questions to ask. In effect, Bødker (2015, 26) argues, the discipline has "just dump[ed] technology on people." Indeed, the inundation of technology has made the participating communities more critical of technology.

These communities also engaged in selective use of IT due to its implications in unsustainability. Baumer and Silberman (2011, 2271) argued that "it is not obvious that the complex conditions associated with unsustainability ... are best addressed with computing technology." Tainter explains that although complex system can be very effective at addressing social problems, such as sustainability, at some point the complexity of the system becomes so great that the returns are marginal (Tainter 2006). If the complexity is left unconstrained, Tainter argues, diminishing returns become negative, meaning the system is ineffective at problem solving, and the system (or society) is vulnerable to collapse. Considering Tainter's argument in the context of sociotechnical systems, Raghavan and Pargman suggest simplifying system complexity through the software concept of refactoring (Raghavan and Pargman 2016). Refactoring software is the process of applying techniques that makes code more efficient and readable, breaking down complex functionality into simpler parts, and limiting external inputs. Applying these same techniques to sociotechnical systems, Raghavan and Pargman argue, could productively address their issues of growing complexity. They provide 22 signs of a society that could be refactored with abstract concepts of how they could be refactored. For example, Raghavan and Pargman explain that removing duplicated code, including code with variations but similar functionality, is a form of software refactoring that can be applied to sociotechnical systems in the sense that similar functionalities can be consolidated. For example, disjointed efforts within an institution to build plant data services for farmers would better serve the institution and the farmers if they were consolidated into an interoperable system.

I argue that the concept of sociotechnical refactoring is particularly appropriate for permaculture communities in part because it overlaps with permaculture practices. Specifically, permaculture aims to limit external inputs to their sustainable polycultures. For example, in a polyculture, nutrients for plants should be provided by other plants in the ecosystem or from on-site compost rather than off-site fertilizer. Therefore, an IT created for a permaculture community that curbs the external inputs into their agroecosystems or information ecology will be better at addressing the community's complex conditions associated with unsustainability than an IT that does not. If no IT can possibly provide a refactoring service to the sociotechnical system, then, as Baumer and Silverman (2011) argued, sometimes the implication is not to design technology.

I argue that another way to address complex sociotechnical conditions associated with unsustainability is to ensure the IT systems empower the communities and provide their members with agency so that they can sustain themselves in the absence of the IT. In earlier work, my colleagues and I describe a self-obviating system which renders itself unnecessary by offering some service that solves or addresses a problem (Tomlinson et al. 2015). In other words, the IT's impacts remain even after it is removed from the information ecology. For example, an IT system that teaches the community how to design sustainable polycultures could facilitate the transition of enough newcomers to full participants to encourage face-to-face social learning as the community norm, rendering the information system un- or less necessary in the long-term as that knowledge becomes a part of the community's sociocultural capital.

Though the information challenges the participants faced are in theory well-suited for technological intervention, many of these permaculture, resistance, technological, and long-term values present serious tensions with adoption of modern ITs. The next section describes those challenges and Chapter 5 explores how to address them.

CHAPTER 5:

SAGE Plant Database

The SAGE Plant Database is an information technology created to support sustainable polyculture creation and to function within grassroots sustainable agriculture information ecologies. To create this database, I worked with the Live Oak and Manzanita communities to address the lack of region-specific plant data needed for sustainable polyculture design in their contexts. This chapter presents the requirements, design and architecture, and implementation of SAGE Plant Database, and ends with a comparative analysis to other plant databases used by the communities.

5.1. Rationale for the SAGE Plant Database

There are many kinds of plant information, not all of which are relevant to agroecosystem design broadly (e.g., plant genomes), or to sustainable polyculture design specifically. Creating a sustainable polyculture design requires a significant understanding of plant relationships and human uses, as described in 1.1. However, as described in 4.1, students struggled with creating a sustainable polyculture design that specified plants, their placement, and their function. The permaculture community draws upon ethnobotany, agroecology, and horticulture for information.

Horticulture simply means "garden cultivation" in Latin, but the discipline has a more specific characterization – "the cultivation, processing, and sale of fruits, nuts, vegetables, and ornamental plants and flowers" in addition to services such as installing and maintaining landscapes (Shry and Reiley 2010). Horticulture requires a working knowledge of the average form characteristics and growth conditions of a plant population (e.g., species). Permaculture plant characteristic data is most similar to the level of detail found in information resources authored by horticulturalists, such as plant nurseries, and gardening websites, and books.

Ethnobotanists and anthropologists have studied ways in which people around the world have classified and used plants for medicine, food, religious ceremony, and other cultural functions. Sustainable polyculture designers use these categories of data and others to choose which plants to include in the polyculture (explained in detail in section 5.3). How people use plants or arrange mutually beneficial relationships among plants in agricultural systems is based upon observation and experience. As described in section 2.1.2 observation and experience are forms of empirical knowledge in activist research. However, such empirical knowledge cannot be found in one place—it is held by individuals or disassociated communities or cultures, or, in this case, members of the participating communities. Much empirical knowledge exists as unrecorded folk knowledge (Ford 1978), and still more knowledge has been lost during the colonialization of indigenous farming communities (Simpson 2004). In addition to horticultural knowledge, I aim to capture the recorded and unrecorded folk knowledge of individuals in the participating communities so that it can be organized and distributed to other and new members.

The intrinsic characteristics that participants most commonly used in sustainable polyculture design were plants form, structure, and seasonal characteristics. Agroecology utilizes similar characteristic data. What participants referred to as "intrinsic characteristics" are known as "functional plant traits" in formal plant sciences (Reich et al. 2003). Functional plant traits include physiological, biochemical, morphological (i.e., form), anatomical, and phenological (i.e., seasonal reproductive) traits (Kattge et al. 2011). Conventional agriculture utilizes functional plant trait data that are favorable for domestication and yield (Martin and Isaac 2017), but agroecologists use functional trait data to choose species or cultivated varieties to reduce detrimental negative and increase productive ecological impacts (Damour, Navas, and Garnier 2017). More recently, agroecology researchers started incorporating functional plant ecology– the study of plant ecology across scales (Shipley 2007; Grime, Hodgson, and Hunt 1988) – through the comparison of species along axes of functional traits to predict plant responses to, and impacts on, surrounding environments (Damour, Navas, and Garnier 2017; Garnier and Navas 2012; Martin and Isaac 2017). For example, functional plant ecology evaluates a plants functional response to drivers of climate change – Trevathan-Tackett et al. (2017) determines the functional traits of sea grass that impacts their ability to sequester carbon. Agroecologists' incorporation of functional plant ecology in the design of agroecosystems is similar to and has the potential to bolster the functional analysis cycles to create the ecological balances necessary to form a sustainable polyculture.

Without access to functional trait, horticultural, and folk knowledge, many newcomer participants to sustainable polyculture design ceased their involvement, concluding the process was too difficult and the learning curve too steep. To help members of the communities engage in sustainable polyculture design, the SAGE Plant Database captures both folk and horticultural knowledge and organizes the relationships among plants and ethnobotanical uses.

5.2. Goals and Requirements for the SAGE Plant Database

The goals and requirements emerged from six forms of qualitative data discussed in Chapter 3 (i.e., observations, design workshops, survey or practitioners, interviews, community-referenced artifacts, and community-created artifacts). For this line of inquiry, I conducted all analytical coding with the intention of determining goals and requirements for the plant database. In this analysis, I assessed the contexts that inform the goals, form, and functions of the database. All coding entailed taking notes in a physical notebook while referencing digital and physical copies of observation notes, design workshop notes, surveys, interview transcriptions, community-authored artifacts, and community-referenced artifacts that were used in, were a product of, or which described participant's agroecosystem design process. The methodological triangulation of these inquiries led to themes for the requirements.

I conducted the first phase of coding by listing high-level agroecosystem design and the implementation activities that participants engaged in. For every occurrence of a high-level activity, such as installing a grey-water system, I identified the fine-grained actions that made up the activity, the tools used in the activity, and contexts the activities occurred in. I translated each fine-grained action, tool, and context into potential goals and requirements for a plant database.

The participants had many goals for the SAGE Plant Database. I identified two overarching themes within the participants' goals: goals that support the agroecosystem design process, and goals that support the communities' ethics and values. All of the goals are presented in section 5.2.1. The participants had many requirements for the SAGE Plant Database. I found two themes among the participants' system requirements: those that specify the plant database's functions and those requirements that support the communities' values. The system requirements are presented in section 5.2.2.

5.2.1. Goals of the SAGE Plant Database

Based on this analysis, the following goals for the SAGE Plant Database were defined by community members or inferred from community and participant values (see section 4.2 about values). Together, the goals specify the role and function of the SAGE Plant Database in the information ecology:

- Represents and informs community plant knowledge
- Maintains high quality data
- Supports social learning

- Supports quotidian insubordination
- Supports evolving community needs
- Supports anti-consumerism
- Supports long-term equality
- Supports environmental sustainability

Participants from the design workshop and those involved in early brainstorming (see section 3.2 on methodology) agreed that the SAGE Plant Database needed to **represent and inform community plant knowledge**, and that this knowledge should be of **high quality**. Its purpose should be to aggregate all the local plant knowledge into one place and allow individuals to use that information, much like their own plant lists, in their sustainable polyculture design process. Many participants were concerned about the quality of plant data in the database and observed that less knowledgeable community members sometimes confused plants because several different plants are referred to by the same common name. This phenomenon is perpetuated by the fact that many gardening resources also omit scientific name or images, which are the most uniform signposts for confirming which plant the information is about.

Although, all participants envisioned the database as an electronic store-house of local plant information, many participants envisioned it doing more than just that. Some participants also envisioned the database as a computer-mediated **social learning** tool. They wanted to connect with and learn from their peers using the database. For example, one participant envisioned a "click here if you're growing" widget to indicate how much of that plant was being cultivated by the community and who was growing it. Many participants wanted to see their peers' techniques for planting, growing, and harvesting, but had varying ideas of how that would manifest. However, most participants fell somewhere in the middle of the spectrum. Some participants envisioned the database as a learning tool, but without the social component. For example, one participant wanted the database to visually display inputs and outputs of the plant and suggest which plants could provide the inputs. Others had a limited view of social-learning, where the social aspect was only the "collaborative" effort to create a knowledge base. Because participants did not all agree on these extra features of the SAGE Plant Database, most of them are not included in the baseline design presented in this chapter. Some of them, however, are under consideration for future work.

On the surface, the identifiable nature of the social-learning concepts for the database, such as knowing who planted what plant in which location, appears to conflict with some participants desire for anonymity. However, a few participants simultaneously valued anonymous engagement and holding community members accountable for the information they provide. One participant explained that they only desired anonymity for sharing their guerilla gardening experiences without being identified for engaging in illegal behavior. This compromise of seemingly conflicting values demonstrates the complex, contextual nature in which participants evaluate their values, and the difficulty of translating those values into contextual goals. To briefly review, the database needs to support the **community as it evolves**, community members in their acts of **quotidian**

insubordination, and the communities' values in **anti-consumerism, long-term equality, and environmental sustainability**.

5.2.2. Requirements

The following requirements emerged when engaging with the community and from the goals. The quality requirements describe what the database is supposed to be, whereas the functional requirements describe what the database is supposed to do.

- Quality requirements
  - Availability - online and offline, export and import data
  - Integrity – data is accurate and authentic
  - Confidentiality – anonymous interaction unless identifying information is authorized for public viewing
  - Sustainability – minimize ecological footprint
  - Interoperability – able to work with other systems that can, for example, recommend companion plants
  - Reusability (Open-source) – all or parts of system can be repurposed for new or different systems
- Functional requirements
  - Provides users with the ability to search and organize data
  - Provides users with ability to add or modify data
  - Provides users with ability to save data
  - Provides a platform for sharing planting, growing, harvesting, and use techniques
  - Provides an API to support future community-designed applications requiring plant data
  - Operates on a range of personal computing devices (old and new, mobile and desktop)

First, participants overwhelmingly desired the database to be **available online** so that it would support collaborative functionality and could be accessible from multiple devices and locations. Participants valued that an online plant database would support the asynchronous collaboration of aggregating local plant data. On the surface, the "collaboration" motivation for this requirement may seem at odds with the participants' resistance to engaging via digital technologies that replaced or reduced face-to-face social interaction, including collaboration. Sharing plant information face-to-face – one person asking another for plant information – primarily occurred between a student and teacher. However, searching for plant information is better suited as a reference task than a social interaction – if the information is available, it is better for a student to look it up them self then ask an educator to act as a dictionary because an educator can make a larger impact spending that time introducing, explaining, and demonstrating complex concepts. Educators and community members printed or emailed plant lists for their pupils and peers so the pupils and peers had the agency to execute their own queries. The social interaction in searching for plant information occurred because, as explained in section 4.1.3, participants found it difficult to find much of the plant information needed for polyculture design. The plant database facilitates the ability of participants to look up plant information themselves.

Many participants thought that the databased should be *also* accessible **offline**. Some participants desired device independence and portability because they use multiple devices and may not have internet access when working. For other participants, an "offline" database fulfilled their desire to have personal copy for quick reference, just as they do with the physical plant lists they currently access, carry and share. For these participants logging into an account or connecting to the internet were large enough barriers to discourage regular use.

Participants wanted to be able to **add** plants to the database and **modify** their attributes. Members of the communities often jotted down notes on the community-authored plant lists that elaborated on attribute information or provided new attribute information about the plant. In effect, they wanted to combine their knowledge with that which was already recorded to make a more-complete knowledge base.

To support offline accessibility and the ability to manipulate or arrange the data independently from the online setting, participants suggested an **export** function. Such a function, some participants envisioned, would enable them to transition exported plant data into personalized plant lists for design projects. Similarly, participants wanted to **import** large amounts of new or modified data back into the database without entering each individual plant attribute through a GUI.

Participants specified two interactions for selecting a plant to include in their design. First, they wanted to **search** for plants by name, both common and scientific. Often times participants in the process of designing a polyculture already had an idea of a plant they could include in their design and looked it up by name on Google, in a book, or in some other resource to confirm or deny that it is a suitable choice. By allowing participants to search the database by name, they could do the same here. Second, participants wanted to **filter** plants by attribute such as height and layer. To select a species, participants consulted plant lists that shared some attribute to get a sense for the range of options. These shared attributes ranged from specific, such as "aquaphilic plants specifically for [Live Oak]", to broad, such as "permaculture plants for temperate climates."

Some participants wanted to the system to automatically **recommend companion plants** for a plant they were browsing. "Companion plant" is a colloquial term for a plant that provides beneficial functions for another plants. For example, lavender is considered a companion plant for apple because lavender deters codling moths (Landolt, Hofstetter, and Biddick 1999), a destructive pest for apple trees. Participants wanted the database to provide companion plant lists because, in practice, they often consulted companion plant lists for ideas of how to make their design more robust.

Some participants wanted the database to **provide a platform for sharing planting, growing, harvesting, and use (i.e., implementation) techniques**. These techniques are based on the plant attributes and the specifics of the environment it is planted in or its use context. Although these techniques pertain to the implementation or use of a sustainable polyculture, they were factors considered during participants' design of sustainable polycultures. For example, participants referred to Toensmeir (2007) for his wide range of information about why plants are desirable to include – they are easy to harvest, store, and propagate – and how they can be used, including tips for planting, trellising, pruning, and cooking. Participants referenced Lancaster (2013, 2007) for water-related specifics of the environment that the plant will be planted in, such as formulas for calculating the water needs of a plant, how to harvest water from a roof, tips for how to plant trees to avoid difficult hole digging in compacted soil, and how to prune trees so that they would cool the temperature of the house in the summer and allow sun to warm a house in the winter.

Participants' wide range of goals for the SAGE Plant Database that are not included in the initial design (see section 5.2.1) should still be considered for future work. To support the future development of applications that expand on the SAGE Plant Database, like the SAGE Composer and other applications described in the Prologue, the SAGE Plant Database needs to have an **Application Programming Interface (API)**. An API is an intermediary that allows applications to interact with each other. Specifically, an API is a set of protocols and tools that, in this case, allows developers to incorporate the information in and functionality of the SAGE Plant Database into other applications.

Participants' use of a wide range of computing devices indicate that the plant database needed to be **operable on a range of personal computers** with varying levels of performance. Several participants were using old machines that were functional but obsolete by their manufacturers' standards. However, these participants felt that their computers were still serving their needs and anticipated using their machines until these machines could no longer do so. Often time those machines can only run software that are several years old. Outdated software systems have unaddressed security risks and are missing other features of modern versions. Designing systems to work with older computers and software in addition to modern versions of the same software on modern computers is a substantial challenge. If there is a great enough difference in the software and hardware architecture of old and new computers, there may not be a way to develop a single system that works on the range of machines.

The database also needs to allow for **privacy** by way of anonymous use and contribution so that participants can feel secure in their use of the database while engaging in acts of quotidian insubordination. To support the communities' anti-consumerism, long-term equality values it must be **open-source**, thus providing equal opportunity for all people to access the database and its data or copy the platform and transform it into something more suitable for their needs. The platform must also be open-source to allow any community to adopt it and modify it into what their specific community needs. And finally, to support the communities' values of environmental sustainability, it should have software, network, and hardware architectures that minimizes its environmental footprint in effort to support **sustainability**.

5.3. Domain Knowledge for the SAGE Plant Database

The domain knowledge (i.e., knowledge about the context that the systems is operating within and supporting) emerged from six forms of qualitative methods discussed in Chapter 2. The domain knowledge represents the context in which the SAGE Plant Database must function and support.

For this line of inquiry, I conducted all analytical coding with the intention of determining domain knowledge for the plant database. Because the community envisioned the database to support sustainable polyculture design, I assessed which plant information was important to participants' sustainable polyculture design process in the first analysis. The coding process was the same as the process described in section 5.2 with data and materials that were used in, a product of, or described participant's agroecosystem design process. The methodological triangulation of these inquiries led to themes for the domain knowledge.

I conducted the first phase of coding by listing details in the notes, transcriptions, and artifacts about plants that are interesting or relevant to the design process. After creating this list, I identified two over-arching themes: context-specific characteristics that every plant should have to be a potential candidate for an agroecosystem, and plant properties that participants consider when configuring the functional composition and spatial placement of the agroecosystem.

I coded the selected notes, transcriptions, and artifacts twice more, focusing each time on one of the two over-arching themes. I conducted the second phase of coding by writing down every context-specific characteristic that participants use to identify if a plant is a potential candidate for agroecosystems. I assessed that these context-specific characteristics represented four inclusion criteria for which plants should be featured in the database. These inclusion criteria are presented in section 5.3.1.

I conducted the third phase of coding by writing down every property of a plant that participants consider when configuring an agroecosystem. I found that these plant properties represented the data property and value fields that make up the plant database object. I grouped these properties into three categories based on the relevance of the property in various stages of the agroecosystem design process. These plant properties are presented in section 5.3.2.

5.3.1. Inclusion Properties

Participants from both communities considered four categories of inclusion properties for plants amenable to sustainable polyculture design. The inclusion properties represent which plants should be included in the database (see Table 9).

Table 9 Domain knowledge – inclusion properties

Inclusion Properties	Description
Climate appropriate	Able to thrive in the local climate.
Provides ecosystem services that appeal to humans	Ecosystem services that humans are interested in, such as food, fiber, and timber. Includes medicinal benefits, being pleasing to the senses, and dye-producing.
Provides ecosystem services that support the local ecology	Ecosystem services that are beneficial to the entire ecology, such as climate regulation, soil formation, and nutrient cycling.
Low maintenance	Require little-to-no care in normal climatic conditions.

There were, however, differences in what constituted climate appropriateness, ecosystem services that support the local ecology, and low maintenance because of the differences in the communities' local ecologies. In other words, a trait that makes a plant low maintenance, for example, for the Manzanita community may not be climate appropriate for the Live Oak community. Such a trait would likely require significant maintenance to survive in the new context, if survival was even possible. The exemplar agroecosystems presented in section 1.1.1 demonstrate the importance of the inclusion properties and how they manifest differently dependent upon the local ecology the sustainable polyculture is designed into.

5.3.1.1. Climate Appropriate

Participants widely agreed that all plants in the database for their community and used in sustainable polyculture design should be **climate appropriate**. For a plant to be a candidate for an agroecosystem, it must be able to thrive in the local climate and be tolerant to local conditions. For example, a plant must be heat tolerant under the normal and extreme climate conditions in the area. To be heat tolerant, it must not succumb to heat stress, which is "the rise in temperature beyond a threshold level for a period of time sufficient to cause irreversible damage to plant grown and development" (Wahid et al. 2007, 200). Weiseman, Halsey, and Ruddock (2014, 95) explain that "most [plants] are limited to a specific range within a specific biome." Biomes are "large naturally occurring [communities] of flora and fauna occupying a major habitat" (Stevenson 2010) with transition zones instead of boundaries. For example, much of Southern California is a chaparral biome containing interwoven drought-tolerant shrubs and bushes (Bornstein, Fross, and O'Brien 2005).

Participants looked for plants that were well suited to thrive in their respective USDA plant hardiness and American Horticultural Society (AHS) heat zones, therefore the plant database should include this information. A hardiness zone denotes a range of annual minimum temperatures. If a plant belongs to that hardiness zone, it can with stand those minimum temperatures without severe damage. A heat zone is defined by the number of days that experience temperatures over 86 degrees Fahrenheit. If a plant belongs to a particular heat zone, then it can survive at least that number of days over 86 degrees. Plants typically belongs to a range of hardiness and heat zones. The Live Oak community, for example, was situated in the USDA plant hardiness zone 9b (i.e., can withstand average annual minimum temperatures between 25 and 30 degrees Fahrenheit) and American AHS heat zone 9 (i.e., can withstand between an annual average of 121 and 150 days each year with temperatures over 86 degrees Fahrenheit).

Participants that designed for personal use on a single site said they narrowed in their interested in plants that could grow in their specific micro-climate, which may have slightly different ranges of conditions than the regionally specified hardiness or heat zones. Take for example the Santa Ana Winds – warm, dry inland desert winds that travel to the Southern California coast. A Southern California resident that lives in a place that is protected from the Santa Ana Winds will have lower temperatures during the wind events than most of the rest of the region. The unusual microclimate of this protected place will accommodate plants that have a lower heat tolerance and higher humidity needs than a location several miles away and exposed to the warm, dry desert winds.

As an example of the importance of climate information, fourteen of the community-authored plant lists and information sheets emphasized climate-appropriate plants. They used terms such as “for Live Oak” to indicate a regional climate appropriateness and terms like “temperate regions” to indicate a broader climate appropriateness. Four of the plant lists specified an environmental niche in addition to the climate, such as "Aquaphilic plant list specifically for Live Oak." Two of the plant lists contained plants grown at specific demonstration sites to indicate which plants were appropriate in the microclimates of those particular properties.

The community-referenced texts likewise emphasized climate-appropriate plants. Many of the community-referenced texts focused on large regions such as such as the North American temperate climate zones (Jacke and Toensmeier 2005a, 2005b; Toensmeier 2007; Ludwig 2015), global climate regions (Mollison 1988), or dryland areas (Lancaster 2013, 2007). However, within the books, the authors specify that the information they provide is more useful to some climate regions than others. For example, Lancaster (2007) provides plant lists for the Tucson area, and Jacke and Toensmeier (2005a, 2005b) specify that their information is most useful for deciduous forests between USDA plant hardiness zones 4 though 7 with some overlap into zones 3 and 8. Bornstein, Fross, and O'Brien (2005) narrowed their focus to a smaller climate region (the state of California).

5.3.1.2. Ecosystem Services that Appeal to Humans

Participants also wanted the database to include plants that **provide ecosystem services that appeal directly to humans**. Typically, the "key species," or focal point, of sustainable polycultures are useful to humans. Participants designate a primary goal for the agroecosystem and choose key species that achieve the goal. For example, if the primary goal of the agroecosystem is to produce half of the family's produce, then the key species need to be high-yielding and food-producing. Participants explicitly valued edible, medicinal, sensually pleasing, and dye-producing key species. Several participants emphasized high-yielding key species for the calories and nutrients they provide.

As an example, the exemplar agroecosystems in section 1.1.1 provided a number of products and services. For example, the key species in the Suburban Central Florida exemplar, including persimmons and avocados, provided food products. The bamboo and sugar cane supporting species provided natural fencing that served as privacy barriers. The bamboo also provided materials for a bench. The passion flowers were aesthetically pleasing in addition to medicinal. The gopher apple attracted interesting wildlife.

Demonstrating the importance of this criteria, seventeen plant lists contained plants that provided products or services to humans. Ten community-authored plant lists focused entirely on edible plants, and six additional lists featured edible plants in addition to non-edible plants. One plant list exclusively featured plants that had medicinal properties, and four others provided information about medicinal plants in addition to other information. Two plant lists provided information about plants that could be used as dyes or fragrances.

All of the community-referenced texts specified the plants' or agroecosystems' products and services to humans. *Perennial Vegetables* (Toensmeier 2007) included edible plants only. *The Edible Forest Gardens* series (Jacke and Toensmeier 2005a, 2005b) series included edible plants and featured non-edibles primarily for their ability to support edibles either directly or indirectly. This series provided a wide range of information on the products and service to human if plants, including which plants were edible and brief descriptions about how they are processed to become edible, the taste of the edible components of the plants, the historic and modern cultural importance of the plants, and their ability to provide shade, privacy, and protection from wind. Other texts also included information about these products but subordinated them to other considerations. For example, *Rainwater Harvesting for Drylands* (Lancaster 2013) and *Create an Oasis with Greywater* (Ludwig 2015) specifications of plant's products and services to humans were secondary to the ecosystem services it provided, specifically in terms of capturing and filtering water. *California Native Plants for the Garden* (Bornstein, Fross, and O'Brien 2005) specify provisions for native human populations and modern cultural services, such as privacy barriers and aesthetic appeal.

5.3.1.3. Ecosystem Services that Support the Local Ecology

Participants wanted to include plants that **provide ecosystem services that support the local ecology**. In addition to services for humans, participants also design agroecosystems to provide ecosystem services that support the local ecology such as stabilizing the soil, bio-remediation, and regulating the air quality.

For example, the exemplar agroecosystems in section 1.1.1 provided a number of local ecosystem services. In the Suburban Central Florida exemplar, the fruiting trees provided both habitat and food for birds. The goldenrod, gaillardia, coreopsis, milkweed, and sunflower attracted pollinators like bees, butterflies, and hummingbirds by providing food and habitat. Trees and large grasses (i.e., bamboo and sugar cane) have intricate root structures that support soil stabilization and oxygen flow. In the Sonoran Desert exemplar, pollinators helped the mesquite tree produce seed pods that wildlife consumed, then left manure behind to fertilize the sustainable polyculture. The desert hackberry, greythorn, and wolfberry provided habitat and food for birds. The mesquite provides shelter to a young saguaro cactus from excessive sun and cold.

Participants call plants that provide regulating and supporting ecosystem services "support species" because, in addition to offering general ecosystem support, they directly and indirectly help the key species thrive (for a review of regulating and supporting ecosystem services see section 2.3.2.2). Support species are typically native and non-native perennial plants that produce the behaviors that an agroecosystem aims to mimic from the ecosystem. Support species attract pollinating and predatory animals and insects, accumulate nutrients, regulates the climate, and produces top-soil. Without support species' ecosystem services, key species would need external input such as fertilization, pollination support, and pest management. For example, without nitrogen-fixing plants in the sustainable polyculture, a human would need to amend the soil with nitrogen.

Seven plant lists contained plants that provided ecosystem services that support the local ecology. Specifically, five lists specified plants that aided in nutrient cycling and soil formation. Four plant lists specified biological control and pollination support by way of providing habitat and provisions for animals and insects that provide those services.

Most of the community-referenced texts feature some plants that provide regulating and supporting ecosystem services. *Rainwater Harvesting for Drylands* (Lancaster 2013) and *Create an Oasis with Greywater* (Ludwig 2015) emphasized plants that contributed to water regulation such as flood regulation and water purification. *California Native Plants for the Garden* (Bornstein, Fross, and O'Brien 2005) emphasized provisions and habitat for animal and insect species, including species that provide pollination support and biological control, as well as plants that provide disturbance regulation, such as hillside erosion control. *The Edible Forest Garden* series (Jacke and Toensmeier 2005a, 2005b) specified a wide range of regulating and supporting ecosystem services, including the production of an allelopathic chemical that keeps some species from growing around it, the "dynamic accumulation" of micro and macro nutrients such as calcium, phosphorous, nitrogen, and potassium, the production of feed for livestock, and formation of habitat for wildlife.

5.3.1.4. Low-maintenance

Participants wanted to include **low-maintenance** plants. Low-maintenance perennials become established in their environment and need only basic care while continuing to offer a yield or ecosystem service. There are some general principles of what kinds of plants are low- or high-maintenance, though there are exceptions. Although some perennials, like strawberries, require frequent care, perennials are generally lower maintenance than annuals because annuals often require seasonal soil preparation and planting, as well as more intensive and frequent fertilization, irrigation, and pest management. However, some annuals (i.e., plants that die within a year of sprouting from a seed), such as self-seeding annual wildflowers, require less maintenance than other annuals. Self-seeding annuals grow from seeds left behind from the previous year's crop, and are thus already in environments that are well suited for them. Invasive species are also sometimes considered low maintenance because they easily grow without human support. However, they can grow so well that they out-compete desired species and become high maintenance as one now has to remove them. Finally, native plants are generally considered low-maintenance because they are well-suited to grow in the local climate.

The exemplar agroecosystems feature plants that can thrive with no additional water or fertilizer inputs from outside what is naturally occurring (see section 1.1.1). For example, the Sonoran annual flowers sprout each spring after the winter rains and do not require supplemental watering. The non-native fruit trees in the Suburban Central Florida exemplar, however, produce better fruit with pruning, extra water during dry seasons, and supplemental seasonal fertilization, though they will likely survive and produce some fruit at a lower level of maintenance.

The community-authored plant lists also prioritized low-maintenance plants. Seven lists had exclusively perennial plants, most of which were fruiting or had medicinal value. Six plant lists had annuals (i.e., live one year), biennials (i.e., live two years), and perennials (i.e., live more than two years), but most of the annuals and biennials included on these lists easily self-seed and were herbs or flowering plants that were native or attracted pollinators. Three plant lists had exclusively annual and biennial plants – mostly plants you find in a vegetable garden – because community members maintained annual gardens in parallel to their sustainable polycultures so that they had a rapid production of food while their sustainable polyculture matures. Perennial plants may not produce enough food or any food at all while they are maturing, which can take many years depending on the species. Four lists emphasized which plants were native.

The community-referenced texts also demonstrate how a plant can require different levels of maintenance depending on context. For example, a banana tree in the region Manzanita is located would typically be high-maintenance because it requires significantly more water than the local climate could provide. However, if a house has greywater output on the south side of the building, bananas could be the ideal species to use up the excess water that doesn't naturally occur there (Ludwig 2015). *California Native Plants for the Garden* (Bornstein, Fross, and O'Brien 2005) demonstrate the low-maintenance characteristic of native plants in their region of origin, for example, specifying that a plant only needs additional water during its first two summers and during long-sustained droughts.

These categories of inclusion properties dictate which plants are featured in the SAGE Plant Database for sustainable polyculture design for each community or climate region. Each of these inclusion properties were represented in both the community-authored and community-referenced artifacts, demonstrating their relevance in both theory and practice. The next section details which plant attributes are used in sustainable polyculture design and therefore need to be defined in the plant database.

5.3.2. Plant Attributes

Participants examined three categories of plant attributes during sustainable polyculture design. The plant attributes describe which information is included about each plant in the SAGE Plant Database. These plant attribute categories represent the data in a way that is intuitive to members of these communities.

Table 10 Domain knowledge – plant attributes

Plant Attributes	Description
Products and services	The benefits that people obtain from the ecosystem, including indirect benefits. Referred to as ecosystem services in formal sciences.
Growing conditions	A plant's needs and tolerances to respectively thrive and survive.
Intrinsic characteristics	The defining characteristics of a plant. Referred to as plant traits in formal sciences.

Mollison (Mollison 1997) and other permaculture leaders and authors (Weiseman, Halsey, and Ruddock 2014; Jacke and Toensmeier 2005b; Hemenway 2009) define these categories of attributes, or ones similar to them, during the functional analysis stage of sustainable polyculture design (see section 1.1.2). As Weiseman, Halsey, and Ruddock (2014, 94) describes, "plant form is diverse to the point of infinity" and "these forms are based upon the species' adaptation to its surroundings." However, it is impossible and unnecessary to capture the entirety of these expansive attributes – participants and permaculture leaders instead consider a finite subset of properties and values that are relevant to their specific design context. This section introduces the range of intrinsic characteristics, growing conditions, and products and services considered during sustainable polyculture design by participants and the resources they consulted.

5.3.2.1. Products and Services

Participants prioritized selection and arrangement of plants in sustainable polycultures based on their ecosystem service, which participants referred to as **products and services**. In the previous section, I demonstrated why participants chose plants to be included in the database based on their ability to provide products and services to human and other ecosystem constituents (see sections 5.3.1.2 and 5.3.1.3). In the context of this section, products and services are data points that need to be defined per plant in the SAGE Plant Database so that the user can make decisions on which plants to include in their sustainable polyculture.

Weiseman, Halsey, and Ruddock argue that ecosystem services are the plant traits that "maintain ecosystem resiliency" and "[if] ecological functions are not in balance, then the overall survival of the guild may be in jeopardy" (2014, 99). Participants typically chose key species for their products, including high-yield and high-calorie foods, medicine, timber, and dye. Participants chose and arranged support species for their services, including nutrient cycling, attracting beneficial animals and insects, mitigating erosion with their root structures, and providing wind breaks, privacy, and shade with thick foliage. For a review of the representation of product and service plant properties in community-authored and referenced artifacts, see the inclusion properties discussion on ecosystem services that appealed to humans and supported the local ecology (sections 5.3.1.2 and 5.3.1.3).

5.3.2.2. Growing Conditions

Participants used plants' **growing conditions** to determine their suitability for the sustainable polyculture. Participants referred to two categories of growing conditions -- a plant's needs and tolerances. Needs are the ideal inputs for a plant so it *thrives*, such as amount of sunlight, amount of water, and amount and kinds of nutrients. Plant nutrient, water, and sunlight needs were crucial to every design and featured in nearly every community-produced and referenced plant lists (Toensmeier 2007; Jeavons 2012; Bornstein, Fross, and O'Brien 2005). Needs are also the ideal inputs for a plant to *reproduce*, such as serotiny. Serotiny is a plant's requirement for particular ecological conditions, such as fire, to release seeds. Tolerances are the conditions that a plant can survive with, including exposure to pests, soil pH, wind, salt, and shade. Participants considered tolerances depending upon the environmental conditions for which they were designing. For example, many participants in the Live Oak community, who are exposed to seasonal hurricanes, wanted to know the wind, humidity, and flood tolerance of a plant, where as Manzanita participants, who live in a Mediterranean costal climate, wanted to know the drought and salt tolerance of plants.

The community-referenced books encouraged assessing a wide range of growing conditions in sustainable polyculture design, almost all pertaining to the soil, water, and sunlight needs of the plants. Soil is the medium in which most plants grow, and the condition of soil determines if a plant will thrive, struggle, or die. Soil is created by organisms, such as fungi, bacteria, and insects, that break down plant debris. The nature and amount of the plant debris and the organisms in the soil, in addition to the local geology, determine the quality and makeup of the soil. Weiseman, Halsey, and Ruddock (2014) encourage a detailed analysis of soil conditions including soil regimes (i.e., the degree to which the soil is sand, clay, and loam), soil pH, nutrients available or missing, salinization, toxic contaminants, and extreme climate disturbances that can drastically alter the state of the soil, such as extended droughts or heavy rains followed by mudslides. Hemenway (2009) argues that in addition to knowing the soil's physical qualities for sustainable polyculture design, it is also important to consider the organisms that build and change the soil, such as bacteria, fungi, worms, and other insects.

Water is the medium through which plants pull nutrients from the soil, therefore the frequency of rain, depth of water table, and drainage of soil define how much and how often a plant can take in nutrients. Lancaster (2013, 2007) demonstrates how to understand and manage water flow across a landscape in ways that are productive for sustainable polyculture growth and production, particularly in regions that experience seasonal droughts. Moreover, he demonstrates how water-managing earthworks without vegetation are ineffective because the soil washes away without plant roots to hold it together.

Plants use sunlight to photosynthesize. Some, however, can tolerate relatively low levels of light while others require far more. Many authors of the community-referenced texts demonstrated how to choose and place plants based on their daily and seasonal sunlight needs and the path of the sun over the sustainable polyculture site (Mollison 1988; Hemenway 2009; Weiseman, Halsey, and Ruddock 2014; Jacke and Toensmeier 2005a, 2005b; Lancaster 2013).

5.3.2.3. Intrinsic Characteristics

Participants also considered plants' **intrinsic characteristics** when arranged plants in a sustainable polyculture design. What participants refer to as intrinsic characteristics are known in formal plant sciences as plant traits (Reich et al. 2003). Sustainable polyculture design incorporates morphological and phenological functional plant traits. However, given the design process and varying degree of participants' formal education in related fields, the level of detail of morphological and phenological traits in a functional plant traits database like the TRY database (Kattge et al. 2011) is beyond the needs and comprehension of most participants in the permaculture communities.

The intrinsic characteristics I observed participants most commonly use in sustainable polyculture design were a plant's height spread and canopy density at maturity, vertical layer in the polyculture (e.g., ground cover, shrub and tree, see Figure 1-2), whether the plant was deciduous or evergreen, seasons of growth, and seasons to collect yield. The intrinsic characteristics helped participants determine the spatial layout of a sustainable polyculture. For example, shorter plants that need shade can grow in the understory of larger evergreen trees.

Participants also consulted **images** for what the plant looked like. Images of plants helped participants process the intrinsic characteristic data and visualize how the species may be used in a sustainable polyculture they're designing. Participants said that images of the plant helped them gain a sense of the aesthetic appeal of a plant, get a sense of the variation of form in a species, and visualize the size in comparison to other species.

The community-referenced materials suggested consideration of a wider range of intrinsic characteristics than I observed participants use regularly in their design process or were featured on community-authored plant lists. The community-reference materials recommended also including life span, years of productivity, root form, time to maturity, time to harvest, places of origin, places of naturalization, places of invasion, grafted versus not, nut-to-shell and flesh-to-pit ratio, and self-fertile versus requiring cross-pollination with another plant. The more-experienced community members that participated in the design workshop (see section 3.2.2) explained that they too considered many of these additional intrinsic characteristics in their personal practice. During instruction, however, a complete list of potentially important intrinsic characteristics was not reviewed. Instead instructors worked with students on their understanding of the complex relationships between plants, only discussing the intrinsic as they were relevant in a case-by-case basis. I included most of these additional intrinsic characteristics in the plant database because the experienced participants of the design workshop emphasized that these were factors they should be considered in sustainable polyculture design.

The goals and requirements presented in section 5.2 and the domain knowledge presented in this section inform my design decisions presented in the next section.

5.4. Design

5.4.1. Design Challenges

There were three significant design and implementation challenges that were encountered in the design of the SAGE Plant Database:

(1) At what level of detail should a plant entry in the database be defined?

(2) How should plant properties from human, individual plant, and ecosystem contexts be represented?

(3) How can differences in how plants are grown across different local environmental conditions be accounted for and do the differences matter enough to sustainable polyculture design that they need to be recorded?

Representing plants at varying levels of detail. When communicating with each other, most participants referred to plants by common names, and many participants did not know the scientific names of the plants they were referring to. Participants had a wide range of education regarding plant sciences, from none at all to graduate level education and common names were used as the shared language between amateurs and experts. In the educational settings I participated in, participants spoke about plants in a common rather than scientific vernacular because many participants were more familiar with plant's common name than scientific.

At times, the common vernacular was so far removed from a reference source that it became hard for a participant to determine the scientific name for a plant from a reference source. If a participant received a cutting of a plant from another community member and its common name is used for any number of distinct species, it becomes more challenging for the participant to correctly identify the plant. For example, participants used the common name "cranberry hibiscus" to refer to both *Hibiscus acetosella*, a sorrel with red foliage with sour-tasting edible leaves, and *Hibiscus sabdariffa*, a sorrel with green foliage and dark red flower sepals that are commonly used for hibiscus tea. Participants that had grown both and were aware of the distinction between them were able to use photos to distinguish which scientific name and plant properties belonged to the plant they were referring to. However, newcomers looking for information on "cranberry hibiscus," a plant they have only heard about but never grown, often conflated the two plants. Despite the communities' frequent use of common vernacular for plant names, the imprecise nature of common names does not facilitate a clear organization of the information within the database. Instead, the plant database should use scientific names for organizing the plant data.

A single species of plant could have many subspecies, varieties, cultivated varieties, or forms. Furthermore, many plants are hybridized across species (i.e., interspecific), across variety (i.e., intervarietal), or across genus (i.e., intergeneric). For example, many citrus trees are hybrids – Persian lime is a hybrid between a key lime and a lemon – *Citrus x latifolia*, and a Meyer lemon is a hybrid between a lemon and a mandarin orange – *Citrus x limon*). Putting plant entries at the most granular level will exclude plants that don't have a species, like intergeneric hybrids (e.g., Rabbage is a hybrid between a cabbage and a radish – *Brassicoraphanus*) or lead to large amounts of redundant data. Subspecies, varieties, and cultivated varieties often have more numerous and significant differences, but the commonalities are typically much greater than the differences. For an extreme example, the only difference in one unique form of a plant compared to another could be the color of the plant's flower, with all other data being the same. For example, *Prunus lusitanica* L. f. *myrtifolia* is a form of Portugal laurel with darker, smaller, slower growing leaves than the base species.

Most plant records are created at the species level, meaning each plant-record name has a distinct scientific name (i.e., *genus* + *species*). To avoid redundancy of information, variations on species such as subspecies, varieties, cultivated varieties, and forms that have few differences from the species it is a variation of should be represented as alternate properties on the associated species plant card. Conversely, species that have significant differences across variations should each have their own plant record. For example *Brassica oleracea*, a species that includes cultivated varieties such as broccoli, kale, cabbage, cauliflower, Brussels sprouts, and collard greens. However, determining the point at which the differences are significant enough to warrant an independent entry into a plant database and the process of evaluating those differences to make that determination are still open questions.

Another challenge lies in the fact that taxonomic classification for some of these plants are disputed – for example plants in the genus *Sambucus,* commonly referred to as "Elder," has long been the subject of classification restructuring because plants within the genus exist in many parts of the word and have significant morphological differences (Applequist 2015). Although plant cards are associated with a scientific name, in these cases, a plant card will need to be associated with multiple scientific names.

Representing multiple plant attribute contexts. When designing sustainable polycultures, plant attributes are evaluated from multiple contexts: intrinsic attributes, ecosystem attributes, and common uses for humans. Some attributes are distinctive to a plant regardless of the ecosystem it is planted in or a human's socio-cultural relationship with it (e.g., taxonomic classification and flower color), and so should be defined without reference to an external context in the SAGE Plant Database. However, the attributes that vary depending on the climate region it is planted in (e.g., sun exposure and water needs) should be defined per climate region. Though there may be differences in attribute definitions at more granular contexts, like microclimates, it is unclear if this level of detail is necessary for sustainable polyculture design.

Humans have *socio-cultural* relationship with plants that dictate how humans observe, interact, grow, and use plants. Ethnobotanical information is subjective and varies depending on the culture and tradition of the human using the plant. Thus, ethnobotanical data requires a different representation in the database from the more explicit and well-defined biological relationships between plants and other ecosystem constituents, including humans. Ethnobotanical properties are collected in text boxes that allow for open-ended responses. Through these data, the socio-cultural values of the content contributors will be embedded in the information in the database.

A plant's relationships with other non-plant organisms in the agroecosystem are often essential in sustainable polyculture design. Many relationships between plants can be directly determined by comparing values of similar or corresponding properties. However, sometimes the relationships among plants are based on their relationship with a third-party organism that is not a plant (see Figure 5-2). For example, one plant may attract an insect while another plant repels that insect. That same insect may be essential to a third plant's ability to complete a successful reproductive cycle. Specifically, wasps are attracted to nectary plants, are believed to be repelled by marigold and eucalyptus, and are essential to a fig tree's reproduction cycle.

Regarding how to represent plant relationships with organisms from other taxonomic kingdoms, I only focus on animals, including insects and humans, in the scope of this dissertation (see Figure 5-2). Other kinds of organisms, such as non-edible fungi and bacteria, also play a crucial role in maintaining agricultural ecosystems; however, their presence was rarely documented in the participating communities and so is set aside for future work. There was one notable exception – a nitrogen-fixing bacterium. However, participants typically transpose this property onto the plants that provide conditions for that bacteria to grow – that is, they considered nitrogen fixation as though it was a property of the plant itself rather than of a bacterium that resides on the plant. In most observations, insects and other animals were classified as pests, forms of disease management, or pollinators. Animals were also sometimes considered ornamental – something pleasing to observe. The database has a list for animals, including insects, containing only the scientific and common name. The plants reference entries in those lists as pest, disease management, or pollinators when applicable. While edible fungi (such as mushrooms) and lichen are often grouped with plants as a category of food (i.e., fruits and vegetables), they are anatomically distinct from plants and would require unique data representation. The database's inclusion of edible fungi and lichen is currently set aside for future work.

Differences in environmental and technological conditions. Environmental and technological conditions (e.g.., sun exposure and intensity, water quality and frequency, soil condition and drainage, and quality of other agricultural products or services) impact what a plant needs to grow. Members of the Live Oak sustainable agriculture community described their difficulty in using most information resources about growing plants because they were often written for temperate or tropical climate conditions. In the tropics, bananas are grown in full sun, not under a tree canopy. However, members of the Live Oak community planted banana trees directly under a canopy tree but in a position to get morning and/or afternoon sun. By doing so, the canopy tree protected bananas from frost during the infrequent but sustained mild freezes in the area – a phenomenon that does not occur in tropic climate regions.

Variations in growing conditions due to environmental and technology contexts are addressed by associating the attribute value to a climate region. A user of the database should be able to filter their searches by environmental context and technological conditions before searching for or contributing tolerance, form, and use properties.

5.4.2. Introducing the SAGE Plant Ontology

To address the design challenges presented in the previous section, I created the SAGE Plant Ontology. Ontologies are theoretical frameworks used to understand the nature of existence (*New Oxford American Dictionary* 2010). In information science an ontology specifies the terms of a subject area and the relationships between terms, for example, in a database (Berners-Lee, Hendler, and Lassila 2001; Gasevic and Hatala 2006; Hendler 2001). The SAGE Plant Ontology specifies the characteristics of a plant used in sustainable polyculture design and the relationship between those characteristics and those of other plants, humans, and other ecosystem factors.

The way people understand information, the world, and life more generally are contextualized by culture, institution, and personal experience. For example, a tree is classified and represented differently in a food-producing farm context versus a lumber industry context, and different again in a home landscape context. Berners-Lee, Hendler, and Lassila (2001) value the varied representations of knowledge in their concept for the Semantic Web, arguing that a singular centralized system for representation is stifling, unmanageable at scale, and limit the questions that can be asked. The SAGE Plant Ontology demonstrates which plant attributes are necessary to sustainable polyculture design as practiced by the participating communities and adds to the greater, ever-expanding collection of plant knowledge representations.

"Plant" is the key term in the SAGE Plant Ontology for sustainable polycultures. Plants in the database are organized into *plant records*. Each plant record includes its scientific name, common names, images, region-specific endemic status, needs and tolerances, intrinsic characteristics, products, and services as represented in Figure 5-1. These attributes are the other terms or categories of other terms in the ontology. These attributes were determined based on the domain knowledge analysis presented in section 5.3.2. As Bowker and Star (1999) explain, that humans spend a large part of their day doing classification work, and even when it is tacit and ad-hoc, it is an effective way to tackle the complexities we face in life. Similarly, there are many ways formal classifications are developed, including formalizing a classification from anthropological investigations into a community's activity (Bowker and Star 1999). I consider the SAGE Plant Ontology

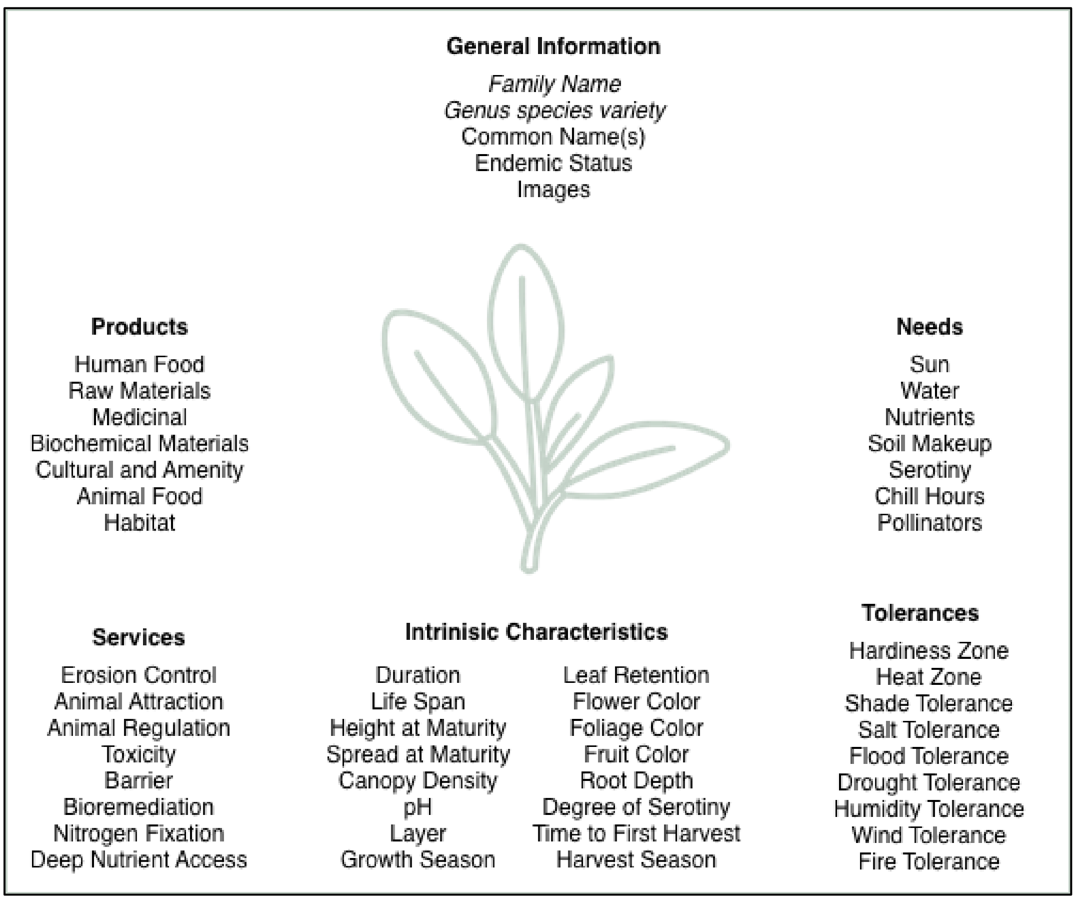


Figure 5-1 Depiction of a plant record.

to be a formal ontology, but one that is under construction. Deploying the first implementation of the SAGE Plant will help determine if the ontology needs to be updated with additional or modified terms and relationships.

The plant attributes that are not intrinsic characteristics represent relationships with other organisms or abiotic environmental factors, such as sun and temperature, as shown in Figure 5-2. The relationship attributes (i.e., needs, tolerances, products, and services) are defined as inputs to or outputs from a plant. The definition of these relationships, while not essential for storing data in a database, is essential to the way the data is interpreted by both users and other systems that will utilize the data for sustainable polyculture design. The plant ontology will allow users of the SAGE Plant Database, and members of the community more generally, to share a common understanding of the structure of the information they are sharing and using. It provides the community with an opportunity to formalize and analyze their domain knowledge (see section 5.3), in effort to advance their efficacy in creating sustainable polycultures and agroecosystems more broadly.

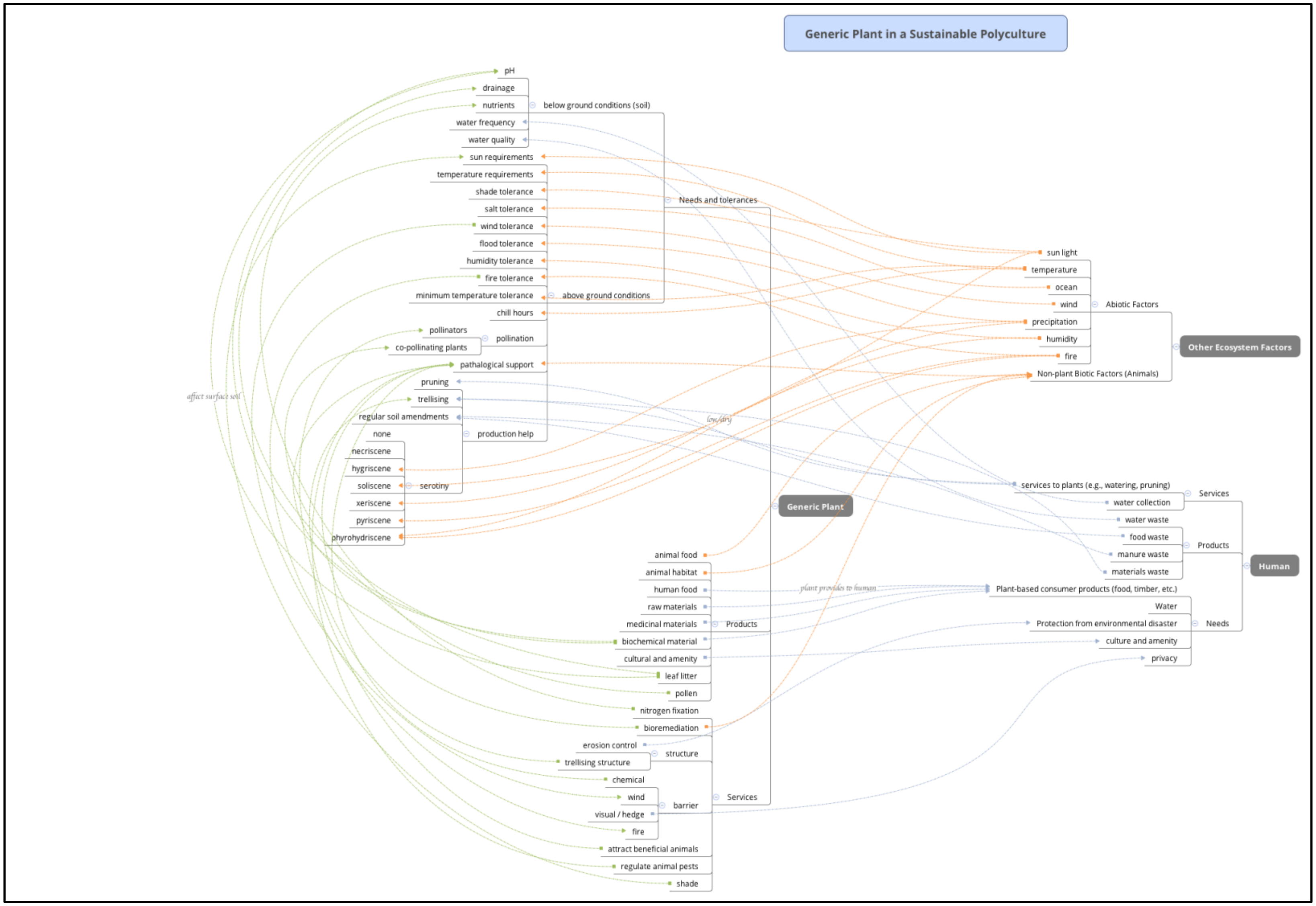


Figure 5-2 SAGE Plant Database representation of a generic plant in a sustainable polyculture.

5.4.3. Technology Adoption Challenges

The communities' values and the design future, including its vision of SAGE, revealed a number of adoption challenges. These adoption challenges could prevent the integration of agroecosystem design and management information systems into sustainability communities. The National Research Council report on Computing Research for Sustainability states "it is in the systems issues in sustainable agriculture that the opportunities for IT seem most salient" (National Research Council 2012). However, there are four significant factors that could cause individuals of these communities to abandon IT:

- reverse adaptation (Winner 1977)
- fragile engagement (Hirano 2015)
- obsolescence (Remy and Huang 2015)
- loss of incentive (Massung et al. 2013)

Reverse Adaptation. Designers' imbue their technologies with values and social agendas, even if unintentionally (Nardi and O'Day 2000; Winner 1977). When users' values and social agendas differ from those embedded in the technology, users may experience "reverse adaptation" (Winner 1977, 229). Reverse adaptation occurs when users adjust their process and conform to the values embedded in the information systems they use. Participants' personal and community values frequently clash with those embedded in the information systems they use, including ones used to look for and manage plant information. Participants reported concern about conforming to the following values in many information systems they use:

- rapid disposal and waste inherent in the value of cutting-edge technology
- information gathering and sharing, lack of privacy, and lack of ownership inherent in the values of customization, open information, and social learning
- constant availability inherent in the value of uninterrupted internet connectedness

Participants engage in degrees of non-use of popular information systems due to the implications of reverse adaptation. The SAGE Plant Database has been envisioned by the communities as an online, open-information, social learning tool. Therefore, this research must ensure that the SAGE Plant Database does not facilitate users' reverse adaptation to values that clash with their own which would likely prevent participants from adopting the technology. The community members' participation in designing the database should imbue the SAGE Plant Database with their own personal and community values and ideally minimize the opportunity for it to be imbued with clashing values.

Fragile Engagement. Fragile engagement is defined as discouraged engagement with IT due to system or task complexity (Hirano 2015). For example, the task of filling a database could become overwhelming and discourage participation. Additionally, newcomers are further challenged by the complications of understanding a plant from an ecosystem context. Members of these communities were overwhelmed or discouraged by a number of technologies they adopted into their practice, but not designed for their use case. I addressed the issue of fragile engagement by designing this database to specifically support the activities and values of these communities.

Obsolescence. Obsolete software and hardware cause many challenges for information system infrastructure. Typically, new information system infrastructures are built using current technology and expected to be used by current technology. However, technologies become obsolete very quickly, and are likely to become even more so in futures characterized by resource scarcity and global change (Jang et al. 2017; Remy and Huang 2015). One-off plant databases pop-up as projects receive short term funding and disappear shortly after the funding period – a huge challenge for data preservation (Rhee and Crosby 2005). Because some members of sustainable agriculture communities insist on using out-of-date technology instead of upgrading, creating tools for this community that can function across a range of computing specifications poses significant design and maintenance challenges.

Loss of Incentive. Temporary incentives for building and using IT can result in superficial engagement with a community. For example, in a 2016 presentation at UCI, Chris Preist explained that payment for participation and gamification "eroded the intrinsic willingness to do a task," which in this case was to close an open door to an air-conditioned building (Preist 2016; Massung et al. 2013). Determining how the participating community could be incentivized to contribute and maintain plant data was and still is critical to the success of the SAGE Plant Database and the community's collective knowledge about plants.

A longitudinal study can potentially assess the range of success and failure in the way I have addressed these adoption challenges. However, such an assessment is beyond the scope of a dissertation. Nonetheless, these challenges must remain at the forefront of this research and have heavily influenced the design and implementation of the SAGE Plant Database.

5.4.4. Introducing the Technology Steward

An essential part of this research is effectively integrating the tools into the community for a positive long-term effect. I argue that this requires the participation of at least one technology steward. **Technology stewards** are people who understand the community's technology needs, have enough experience in technology, and would like to take leadership in addressing those needs (Wenger, White, and Smith 2009). Technology stewards take responsibility for the community's technology resources for a time.

The primary goal of the technology steward is to address each of the possibilities for abandonment. The technology steward should address reverse adaptation through an iterative interaction design process with community participants to ensure that the community values continue to be reflected in the technology. The technology steward should address fragile engagement by offering workshops for learning how to use the database to newcomers. The technology steward should address obsolescence by using frameworks that are well-established and have an active community, are well-documented, work across a wide range of platforms, and upgrade with relative ease. In an effort to address loss of incentive the steward should assemble what I call a "homegrown crowd" to source the data for the region-specific plant database so that the crowd has an invested interest in the database. "Homegrown" denotes that the crowd can be built by the community (i.e., via technology steward and supporting community members) and be composed of members of the community (see 5.4.5 for more information about the "homegrown crowd").

In summary, the primary responsibilities of a technology steward in this context are to (1) build the plant database, (2) create a "homegrown crowd" to populate the plant database, (3) teach community members the how to use the tools, and (4) provide a development team with feedback. In this arrangement, a technology steward is a full-time commitment.

5.4.5. Data sources and quality

There are many resources detailing plant information, but each information resource is created to serve a unique purpose. As discussed in 4.1.3, plant information specific to some climate regions is not available from easy-to-access resources. The information that is available is distributed across many resources. Sometimes this information exists only with the long-time members of a community that have extensive experience in that region.

There have been several attempts to build plant databases that aggregate this information, especially in the permaculture movement. One was a crowdsourced database that suffered from low participation and incorrect data, and has since been abandoned ("Practical Plants" 2013). A more successful database, Natural Capital Plant Database (Natural Capital Plant Database 2018), has a small team of researchers comb through academic and extension publications and information sheets for plant data. However, one of the creators of the Natural Capital Plant Database reported that this process is expensive and time-consuming, making it difficult to expand their corpus of plants for the Midwest to other climate regions, which makes this database less suitable for people elsewhere. Furthermore, the Natural Capital Plant Database does not consider region-specific differences in plant needs and growing methods.

Acquiring the distributed data and creating the non-existent data will require extensive participation from the "homegrown crowd" – the communities the SAGE Plant Database supports. The homegrown characteristic should further embed the community's cultural norms and values into the database.

Through a combination of careful selection and directed snowball recruitment (i.e., using a small crowd to recruit more participants, for example, through their social networks), a homegrown crowd could be appropriately diverse, independent, and decentralized for capturing and aggregating plant data, making it well suited to enact quality control. The homegrown crowd could be *diverse* in areas of interest regarding production and use of plants, level of expertise in their areas of interest, daily professions, age, and, to some extent, values regarding plant production and uses. Several ethnic groups and cultures were represented in the participating community, however most community members were white males and females from the United States. Through directed snowball recruitment in which the initial participant pool represents diversity in practice, socioeconomic status, culture, gender, age, and race, the homegrown crowd could be extended beyond the permaculture communities to include anybody who is growing plants in the region the community is located, and potentially maintain diversity.

Members of the homegrown crowd should be *independent* in the sense that members live and practice their trade in separate locations, only joining together when they choose to, like at monthly social-educational events. This independence allows for the crowd to obtain new perspective and information and continue to grow its collective intelligence. Extending the homegrown crowd to the region the community is located within can further ensure the crowd's characteristic independence.

The homegrown crowd should be *decentralized* in the sense that nobody is forcing participants of the crowd to engage in the crowd nor force which decisions to make about a data point. The database is a place to aggregate the individual decisions into a collective decision.

The plant database needs to be full enough so that users can find plants that meet filter criteria. However, at any given time, there will be many plant records in the database that are not complete. For the crowd to collectively determine a datum, thus ensuring the quality of the data, the same query could be sent to many people in the crowd in an effort to find accurate datum through consensus.

However, with potentially tens of millions of data points in the database, a small homegrown crowd cannot collectively determine every datum in the database. One option is to exhaust other methods of gathering data before utilizing the homegrown crowd. For example, the database can import data from relevant plant databases that support the distribution of their data (e.g., USDA). Another example is to utilize a crowd that does not consist of community members from Mechanical Turk, for example, to crawl community-referenced websites and texts for data. Off-loading the work of the homegrown crowd onto import scripts and non-affiliated crowds allows the homegrown crowd to focus on seeding the plant database with folk knowledge from within their community.

The crowd's collective intelligence should be used to address the challenge of seeding the database with folk knowledge by framing the challenge as a cooperation problem rather than a collection of cognitive problems. Framing database seeding as a cooperation problem requires individuals in the crowd to factor in what other people are doing to make decisions that have mutual advantage. The technology steward can facilitate seeding the plant database with datasets that crowd members may already have. After importing their personal lists, crowd members can choose to add data that benefit themselves and their peers. For example, if the database has a lot of entries for nitrogen-fixing plants but few on plants that attracted pollinators, it would be mutually beneficial for the member and the crowd if the member adds data for pollinators rather than nitrogen-fixing plants. Similarly, crowd members can choose to recruit others for their local plant knowledge that is not already represented in the database (i.e., directed snowball recruitment).

Solutions to cooperation problems often require trust and are often built upon cultural norms and conventions to regulate behavior (Surowiecki 2005). Members of the crowd will have to trust each other to put in data that they believe is of good quality. Adding data of poor quality, including data that does not reflect the community's cultural norms and values, is mutually detrimental to the person who added the information and to the rest of the crowd because both in-turn use that information to make decisions in their sustainable polyculture designs.

The crowd's collective decisions on individual data points is likely more appropriate for addressing issues of quality control (i.e., when a value of a plant property is disputed) than to seed the entire database. If a datum is under disagreement from a small subset of the crowd (i.e., several people are designating different answers for a data point), it should be flagged as a point of conflict. A query for this datum should then be dispatched to a well-formed subset of the crowd so that their collective wisdom can be used to gauge which is the correct answer.

Search-misses should be addressed by both individual or collective decisions. A search-miss occurs when a user searches the database for a plant or property that the database does not have. The user could then opt to enter the datum, thus creating an individual decision. By entering their own data, some users will join the crowd for their first time, thus growing the size of the crowd. If many misses occur for a specific search criterion, the system could dispatch queries to the crowd for that plant or property. The crowd will collectively decide on a value for this datum, increasing its likelihood of being correct. A dispatching system should not query the crowd for all data points that are search-misses because the crowd could become overwhelmed with requests while the database is sparsely populated.

For both users and crowd members, the lack of data in the database during its infancy increases the possibility of fragile engagement. Due to the potential for fragile engagement, the order in which to tool is introduced to various parts of the information ecology may be crucial.

5.4.6. Wireframes of the SAGE Plant Database

This section described current design of the SAGE Plant Database. To conclude this section, I present wireframes of the SAGE Plant Database based on the goals, requirements, domain knowledge, and design presented in this chapter. Figure 5-3 shows a list of all plants and a step-by-step process of adding a plant. Figure 5-4 demonstrates how a plant can be added to the database through the GUI. Figure 5-5 demonstrates how search results can be filtered for specific properties, such as all plants with the vertical layer property set to ground cover.

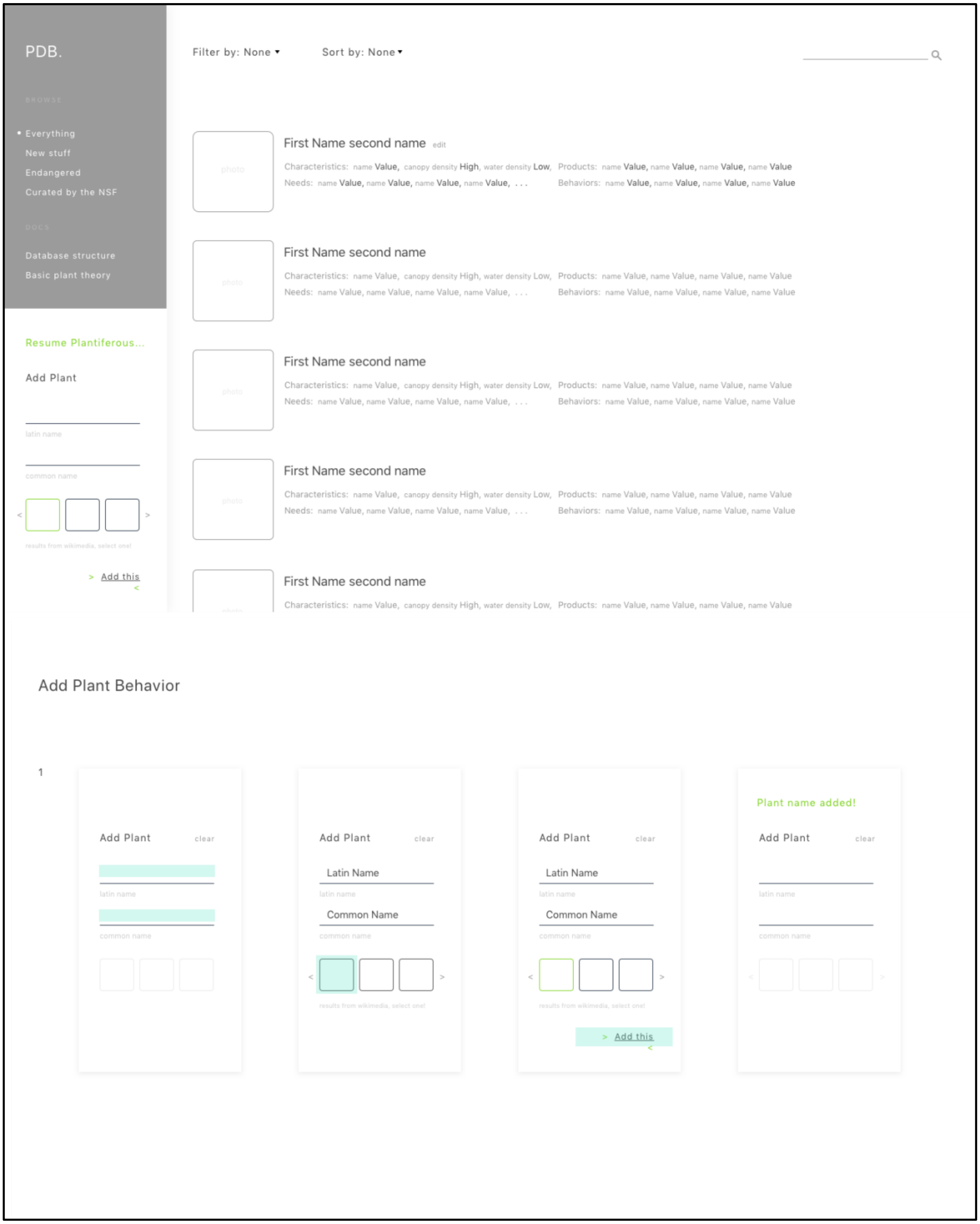


Figure 5-3 Top – wireframe of a list of all the plants in the SAGE Plant Database and an activated add plant function. Adding the plant happens in the bottom left corner of the web page. Bottom – step-by-step process of adding a plant. Wireframes created by Sahand Nayabaziz.

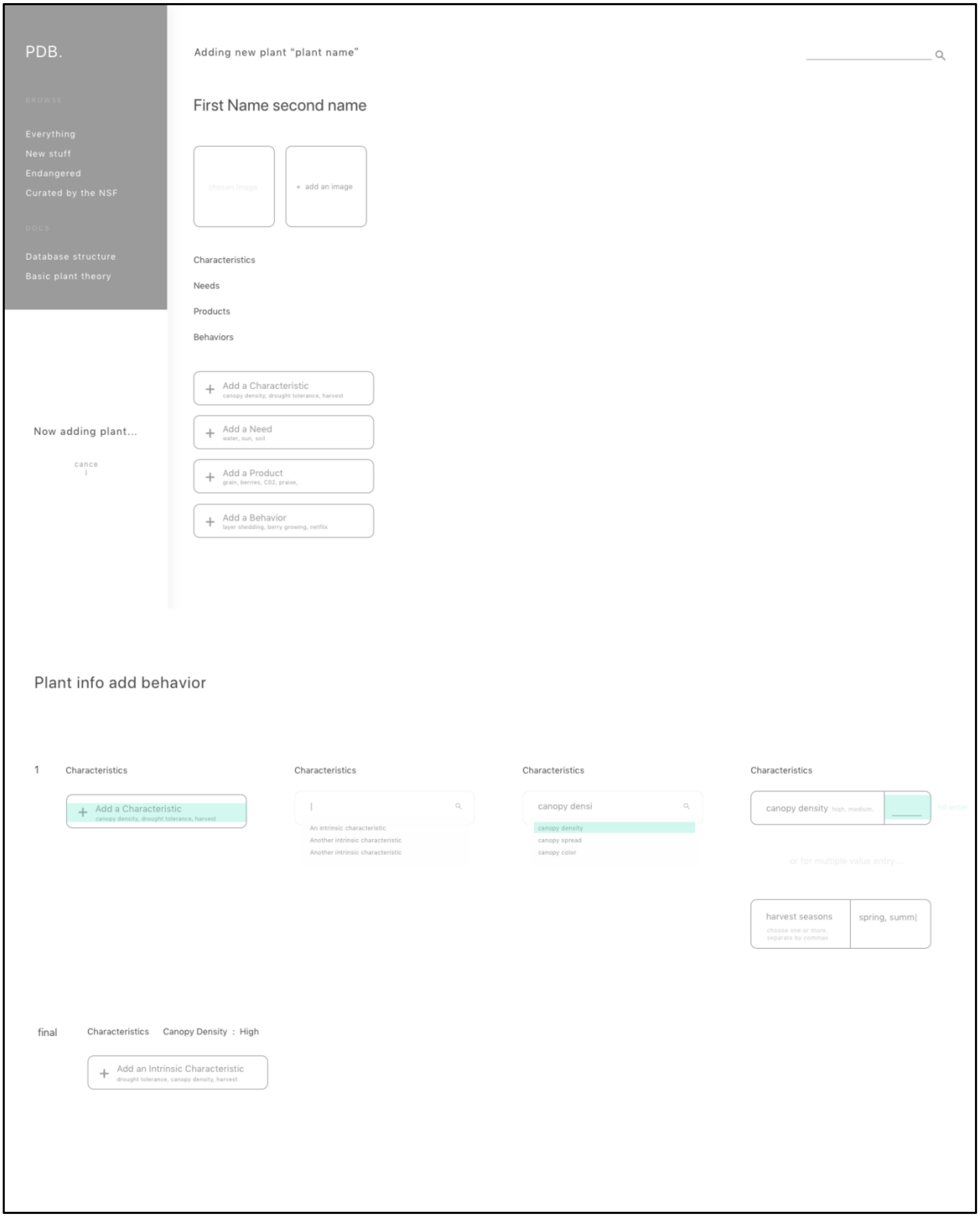


Figure 5-4 Top – wireframe of the page for adding or updating plant information. Bottom – step-by-step process of adding plant information. Wireframes created by Sahand Nayabaziz.

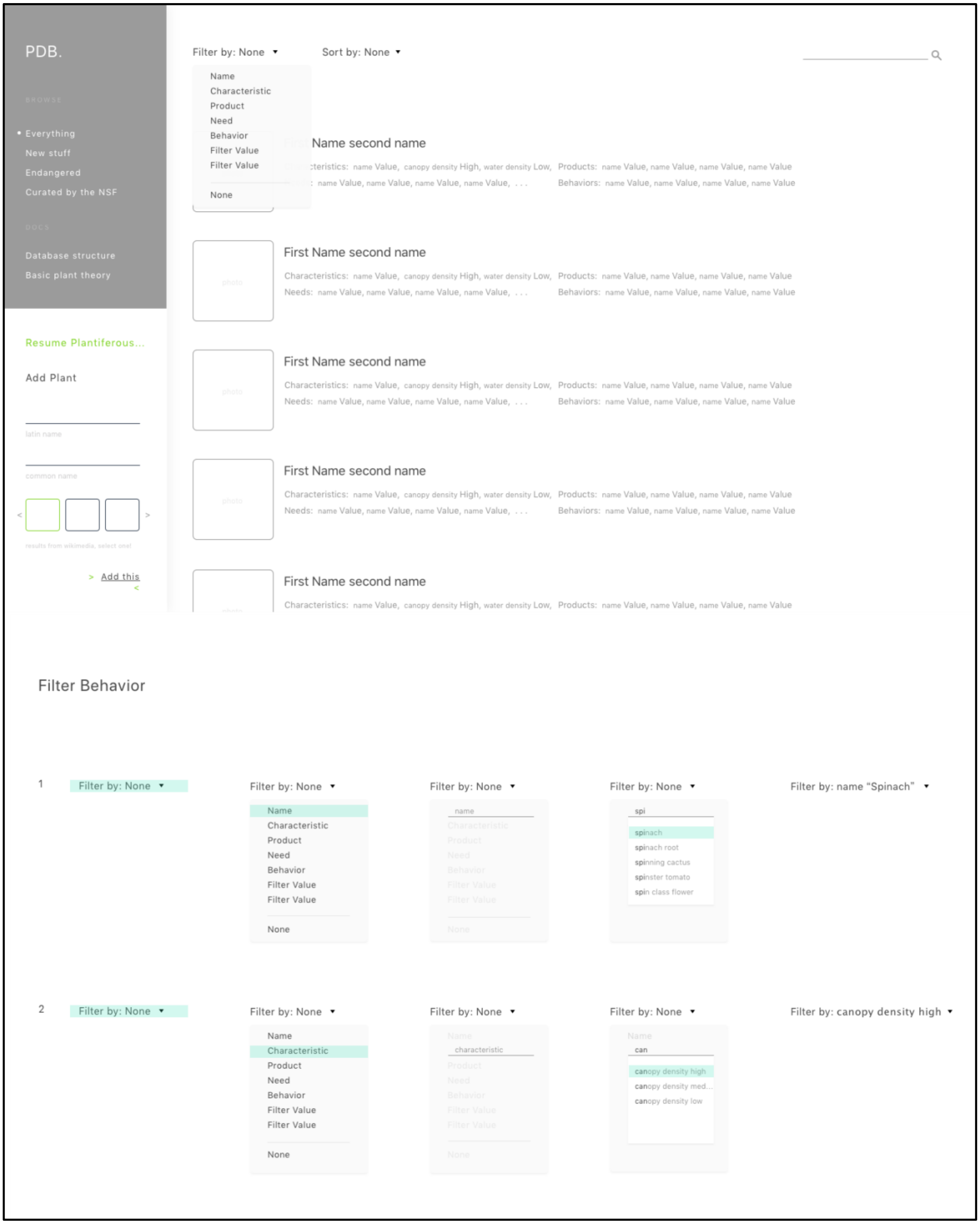


Figure 5-5 Top – wireframes for filtering results for specific properties. Bottom – step-by-step process of the filter function. Wireframes created by Sahand Nayabaziz.

The SAGE Plant Database is still undergoing implementation cycles. section 5.6 details the state of implementation of the SAGE Plant Database. The next section presents a comparative analysis of the *design* of the SAGE Plant Database to the other plant databases that I observed participants use during sustainable polyculture design. Afterwards, I present the current implementation of the SAGE Plant Database.

5.5. Comparative Analysis

This section presents a comparative analysis of the SAGE Plant Database design and five other online plant databases (Table 11). Only four of the other databases were used by participants in their agroecosystem design or maintenance process. I studied participants' use of these four other databases and they did not support participants' specific goals and requirements (see section 5.2) nor domain (see section 5.3). Participants did not use the Natural Capital Plant Database, but I included it because it is similar to SAGE in the sense that it also aims to support agroecological design. Initially, participants did not use the Natural Capital database because they did not know it existed. Yet after I introduced participants to the Natural Capital Plant Database, to my knowledge, they still did not use it. While I do not know if or the reason each participant did not adopt the Natural Capital Plant Database, some reported that they were not willing to pay the fee, and others felt that it was limited in the data for their community's region. This comparative analysis demonstrates how the SAGE Plant Database design is uniquely and comparatively suited to support participants of this research in agroecosystem design and maintenance.

Table 11 "Other databases" evaluated in the comparative analysis

Name	Type	Observed Participant Use
CalFlora	Plant Database	Yes
USDA Plant List of Accepted Nomenclature, Taxonomy, and Symbols (USDA PLANTS)	Plant Database	Yes
University of Florida Institute of Food and Agricultural Sciences Electronic Data Information Source (UF/IFAS EDIS)	Publication Database	Yes
Tree of Life Nursery (ToLN) Plant Information	Document Database	Yes
Natural Capital Plant Database	Plant Database	No

CalFlora, USDA PLANTS, and Natural Capital Plant Database are plant databases, meaning a collection of interrelated plant data stored and organized so that users can easily access, manage, and update the information. In this context, a user can search and organize plant data by plants' forms, functions, behaviors, and/or growing conditions. UF/IFAS EDIS, and ToLN Plant Information are collections of publications and other written materials on a website.

I present the activities supported by and values embedded in the other databases and demonstrate how they differ from the SAGE Plant Database design. The variance in activities make a difference to the design of online plant information resources, warrant the different set of SAGE Plant Database design requirements and goals from the other databases, and justify the need for varying kinds of plant information resources, each supporting a specific community or function.

The remainder of the section reports my grounded comparison of the SAGE Plant Database design to the other databases. To the best of my knowledge there are no existing comparative analyses of plant databases, particularly databases with information used in agroecological design.

This analysis follows Nardi et al.'s (2011, 28) proposal for Comparative Informatics – "the application of the comparative method to the study of information and communication technologies (ICTs) across diverse contexts." Comparative Informatics "aims to create and promote a global program of inquiry in which the analytic gaze may come to rest on any IT practice anywhere" (Nardi, Vatrapu, and Clemmensen 2011, 32). Many of the other databases were developed for applications outside of agroecosystem design and the permaculture context. However, reflecting on their use in an external context can offer insights beyond those offered by the dominant lifecycle contexts of similar ITs.

Comparative analyses, in general, are used to identify significant distinctions or similarities that may lead to generalizations (Rihoux 2006). The outcomes of comparative analyses depend on the frame of reference, observed values, and the assessor, and thus should not be regarded as an objective reality (Pickvance 2003). Comparative analyses can be used to make generalizations when the sample size is large and can be subjected to quantitative assessment. However, some data are only available from detail-oriented, qualitative case studies, which tend to be low in number and are sometimes not conducted for the subsequent comparative analysis (Rihoux 2006). This research engages in caseoriented qualitative comparative methods rather than a variable-oriented statistical methodology (Ragin 2014).

Qualitative Comparative Analysis (QCA) considers each individual case as a complex entity that need to be holistically understood and considered in the course of an analysis (Rihoux 2006). For QCA with few cases, such as this one, cross-case analyses are "sufficiently detailed with-in case studies" (Rihoux 2006, 689).

I compare and contrast the type and quantity of the information and user experience features of the SAGE Plant Database design and the other databases in the context of sustainable polyculture design. This comparative analysis employs a theoretical user's perspective as the frame of reference, in which the user is a generic member of the participating permaculture communities that practices sustainable polyculture design and maintenance. I only assess technical details apparent from a user experience and excluded details only apparent to a back-end programmer. I do not include most technical operational details in the analysis because the goal of this research is to support the activity of agroecosystem design in grassroots sustainable agriculture communities, and also because parent organizations of most of the assessed databases do not make the technical operational details of their databases available.

The other databases are not designed for use in sustainable polyculture design and maintenance with the exception of the Natural Capital Plant Database (see Table 12). However, there are some aspects of the data these systems provide that are useful for sustainable polyculture design and maintenance.

Table 12 The intended application of SAGE and other online plant information resources

Name	Intended Application	Types of Plants	Regions
SAGE Plant Database	Agroecosystem design	Agricultural, ecologically supportive, human useful, and native plants	Southern California
CalFlora (2014)	Public education	Wild plants, both natives and weeds	California
USDA PLANTS (2018)	Land conservation	Vascular plants, mosses, liverworts, hornworts, and lichens	U.S. and US Territories
UF/IFAS EDIS (2018)	Academic and public education	Flowering, landscape, native natural area weeds, seeds, forest vegetation, weeds, wildlife forages	Florida
ToLN Plant Information (2018)	Public education	California native plants	California, emphasis on Southern California
Natural Capital Plant Database (2018)	Agroecosystem design	Ecologically supportive, human useful	World, emphasis on North American Mid-west

In the following sections, for each Comparison Artifact, I describe its properties, present its limitations specifically in relation to their use in sustainable polyculture design and maintenance, and compare its properties and data to properties and data in SAGE Plant Database design (see Table 14 for an overview). This section concludes with a comparison of the human values embedded in the other databases in comparison to those embedded in the SAGE Plant Database design.

Table 13 Summary of limitations of other databases

Information Resource	Primary Limitations
SAGE Plant Database	Limitations are currently unknown because it has not been fully implemented and tested.
CalFlora	Lacks form, ethnobotanical, and ecosystem service data needed to include California Wild plants in an agroecosystem design.
USDA PLANTS	Contains plant property data for relatively few species and lacks region-specific growing requirements.
UF/IFAS EDIS	Lacks a robust search and filter mechanism for plant data with the document style presentation of information.
TOLN Plant Information	Contains only a small number of native plants, omits pertinent details regarding the growing conditions, use, or form, and lacks a robust search and filter mechanism for plant data given the document-based presentation of information.
Natural Capital Plant Database	Is proprietary and pay-to-use. Lacks region-specific data and a public API.

5.5.1. CalFlora

CalFlora is an appealing resource for identifying and locating California wild plants because of the interactive distribution map, plant photographs, and listing of observed locations. These plant data are populated by registered contributors, both professional and amateur plant enthusiasts, and staff. Registered CalFlora uses submit their observations of California wild plants with photographs, which are in turn used for conservation research, education, and curious exploration. Plant photographs are also pulled from CalPhotos, a carefully curated image database of “natural history subjects” such as plants, animals, and landscapes.

Users of the website are encouraged to create an account for browsing so that the developers can collect usage data necessary to acquire funding to improve on the tool. Users that contribute data must also have an account. Contributing users can interact by providing feedback on peers' observations. For example, a user can tell a peer if they believe they have misidentified a plant. Contributing users can also form groups with peers that have a similar interest to share existing and unpublished data.

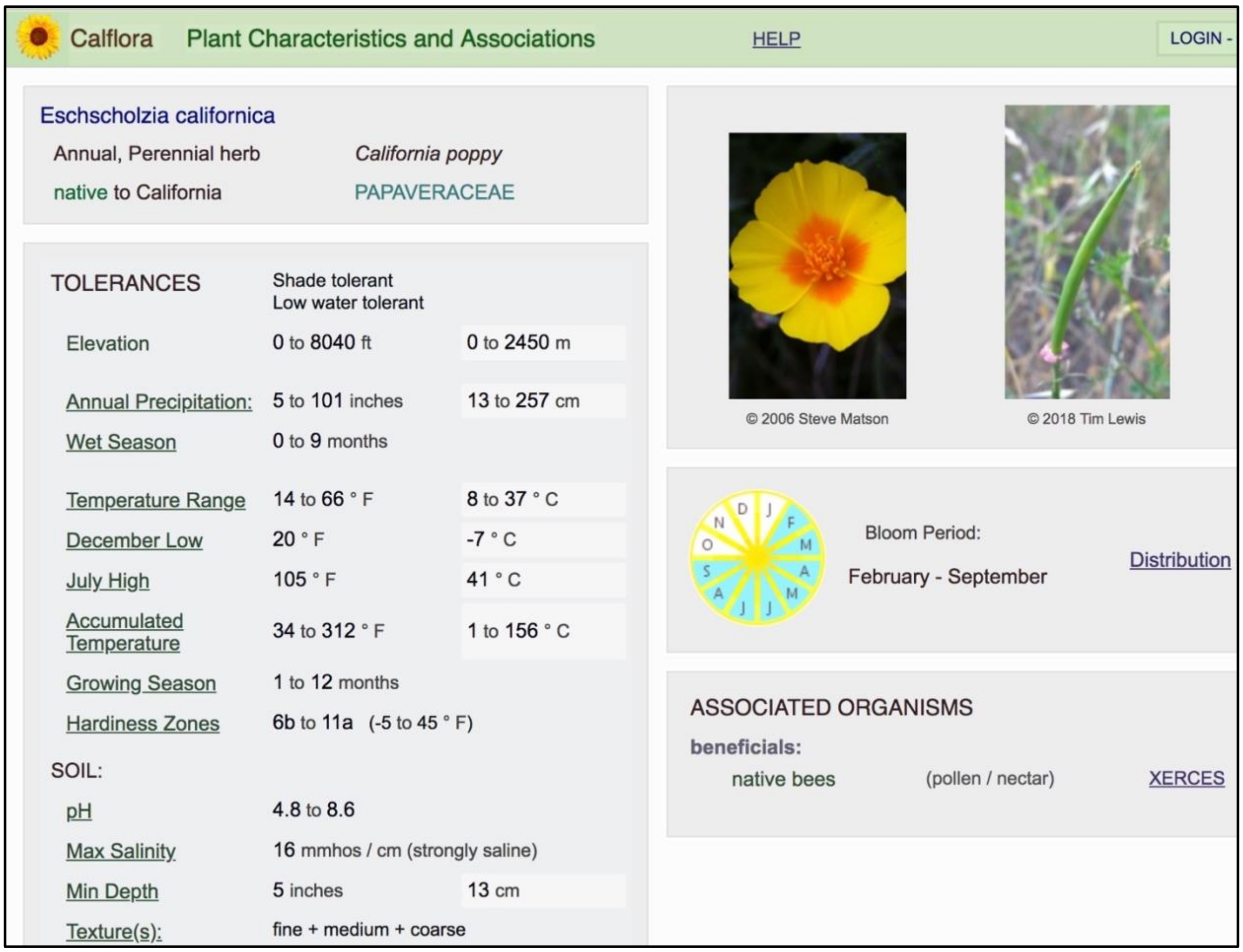


Figure 5-6 CalFlora (2014) plant characteristics and associations for the California poppy (*Eschscholzia californica*). The plant characteristics consist of basic tolerances, soil requirements, and bloom period. Each plant has list of associated organisms, if any, and set of photos pulled form CalPhotos. The photos are the primary indicator of a plant's form.

CalFlora lists each plant's associated beneficial organisms, such as bees and butterflies. CalFlora has some data about plant tolerances, primarily in regard to soil characteristics, temperature, and rain. However, the database provides no ethnobotanical data, such as whether it is food producing. The lack of ethnobotanical information requires users to search other information resources to determine if a plant will provide them with products or services.

CalFlora's advanced search allows a user to search and filter the data based on most available plant data points, making it easy to search for California wild plants in a specific county and microclimate. CalFlora's data cannot be exported. However, search

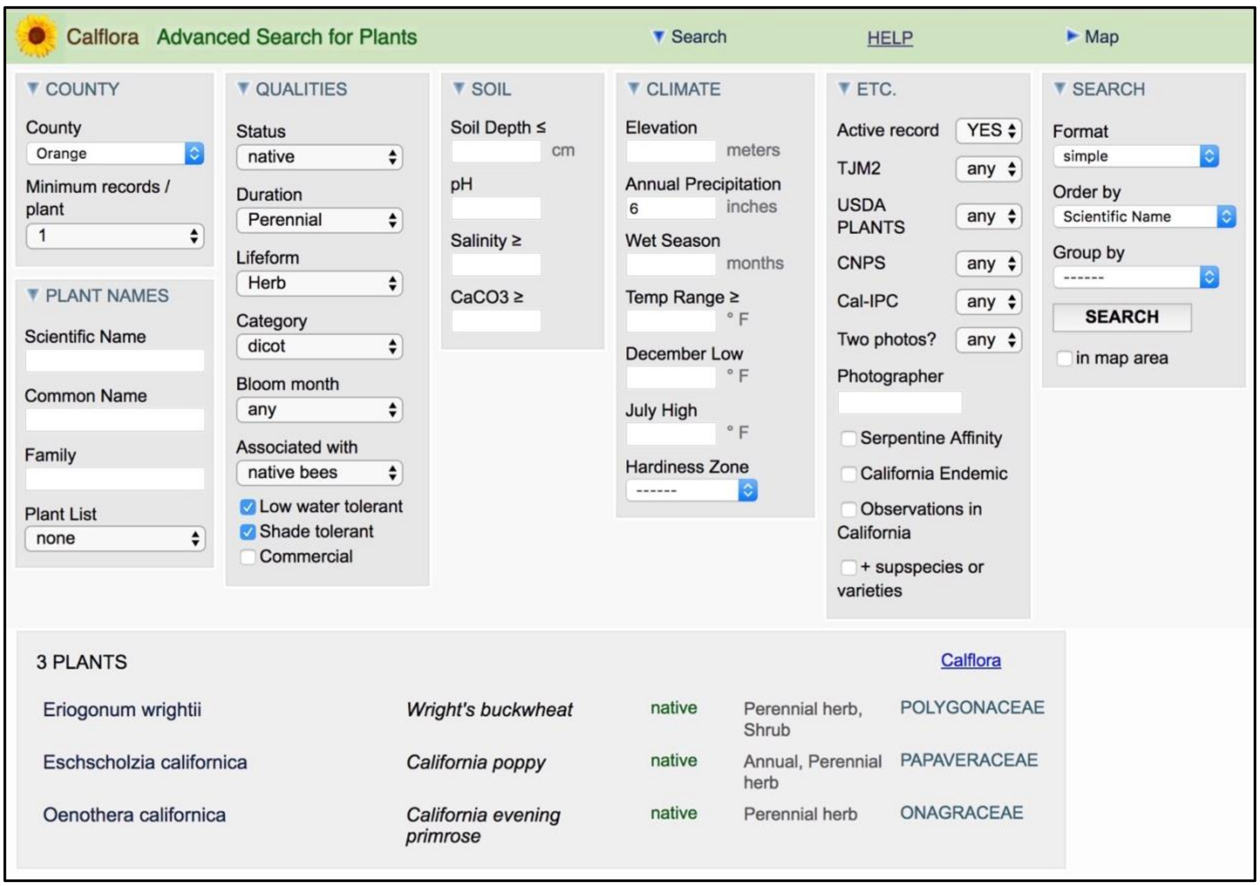


Figure 5-7 CalFlora (2014) Advanced Search. The advanced search, nor a link to it, cannot be found on the home page, but it is CalFlora's most comprehensive search tool for the database. This image demonstrates all of the possible search criteria and represents most of the available plant attributes.

results, containing taxonomic rank, common name, status, life form, and family, and plant information pages are formatted as text and can be copied and pasted into a spreadsheet, though this process would be long and tedious for collecting large amounts of information.

The primary limitation of the CalFlora database is the lack of form, ethnobotanical, and ecosystem service data needed to include California Wild plants in an agroecosystem design. In contrast, the SAGE Plant Database is designed to provide ethnobotanical and ecosystem service data of California wild plants. This is important in agroecosystems because wild plants can be used as alternatives to traditional agriculturally productive plants in effort to cater to the animals and insects that depend on native flora for habitat and food. SAGE is also designed to include form data useful in assessing spatial constraints and opportunities of an agroecosystem design. For example, a user might search plants that create an overstory vertical layer, but without form data they cannot determine which trees would make a good overstory. In addition, while CalFLora has growing condition data limited to wild, unmanaged, or native ecological context, the SAGE Plant Database is designed to include growing condition data beyond CalFlora's tolerance and soil data so that users can understand how to care for California wild plants in maintained, mixed agricultural landscape.

5.5.2. USDA PLANTS

The data found in USDA PLANTS is sourced from an extensive network of federal partners and institutions and is curated by the small National Resource Conservation

Service (NRCS) National Plants Data Team. It is an expert resource because the data is derived or validated through research efforts.

USDA PLANTS has an extensive list of plant attributes it catalogs including distribution, taxonomy, ecology, legal status, morphology/physiology, growth requirements, reproduction, and suitability/use data. The database can be searched by over 120 attributes. All search results can be exported to a comma separated value file.

Although there are nearly 50,000 plants in the PLANTS database, only about 2,000 plants, all of which are plants used in conservation efforts, have defined "characteristics data," mostly consisting of intrinsic characteristics but also including some tolerances, products, and services (see the Appendix for a complete list of USDA Characteristics Data). A search for most agricultural plants, like fruit trees, will have hardly any data available. For example, the PLANTS database only returns 28 plants that grow in in the county the Manzanita community is located in that are palatable to humans, not because there are only 28 palatable plants that grow in that county, but because those are the only plants that have "human palatable" data.

The primary limitation of the USDA PLANTS Database is the incompleteness of the data set. The USDA PLANTS Database is only populated by staff and partners, and not by average users. Their data population method ensures level of quality control that crowdsourced data could not. However, for the permaculture communities, such a level of quality control is not essential because they are engaging with small-scale systems with lower financial risk than industrial agriculture or regional conservation efforts. The SAGE

Scientific Name	Common Name	County	Berry/Nut/Seed Product	Palatable Human
Acer macrophyllum	bigleaf maple	CA(	No	Yes
Brassica juncea	brown mustard	CA(	No	Yes
Brassica rapa	field mustard	CA(	No	Yes
Cichorium intybus	chicory	CA(	No	Yes
Claytonia perfoliata	miner's lettuce	CA(	No	Yes
Cucurbita foetidissima	Missouri gourd	CA(	No	Yes
Helianthus annuus	common sunflower	CA(	No	Yes
Hesperoyucca whipplei	chaparral yucca	CA(		
Yucca whipplei			No	Yes
Hordeum vulgare	common barley	CA(	No	Yes
Juglans regia	English walnut	CA(	Yes	Yes
Medicago polymorpha	burclover	CA(	No	Yes
Medicago sativa	alfalfa	CA(	No	Yes
Mirabilis multiflora	Colorado four o'clock	CA(	No	Yes
Najas flexilis	nodding waternymph	CA(	No	Yes
Perideridia gairdneri	Gardner's yampah	CA(	No	Yes
Pyrus communis	common pear	CA(	Yes	Yes
Rhamnus crocea	redberry buckthorn	CA(	Yes	Yes
Ribes roezlii	Sierra gooseberry	CA(	Yes	Yes
Rosa californica	California wildrose	CA(	Yes	Yes
Rosmarinus officinalis	rosemary	CA(	No	Yes
Salix lucida ssp. lasiandra	Pacific willow	CA(	No	Yes
Sambucus nigra ssp. canadensis	American black elderberry	CA(	Yes	Yes
Secale cereale	cereal rye	CA(	No	Yes
Sidalcea neomexicana	salt spring checkerbloom	CA(	No	Yes
Taraxacum officinale	common dandelion	CA(	No	Yes
Tragopogon porrifolius	salsify	CA(	No	Yes
Typha angustifolia	narrowleaf cattail	CA(	No	Yes
Umbellularia californica	California laurel	CA(	No	Yes

Figure 5-8 USDA PLANTS (2018) Database search criteria for human-palatable plants that grow in the region the Manzanita community is located within returns 28 plants. The county has been removed for anonymity.

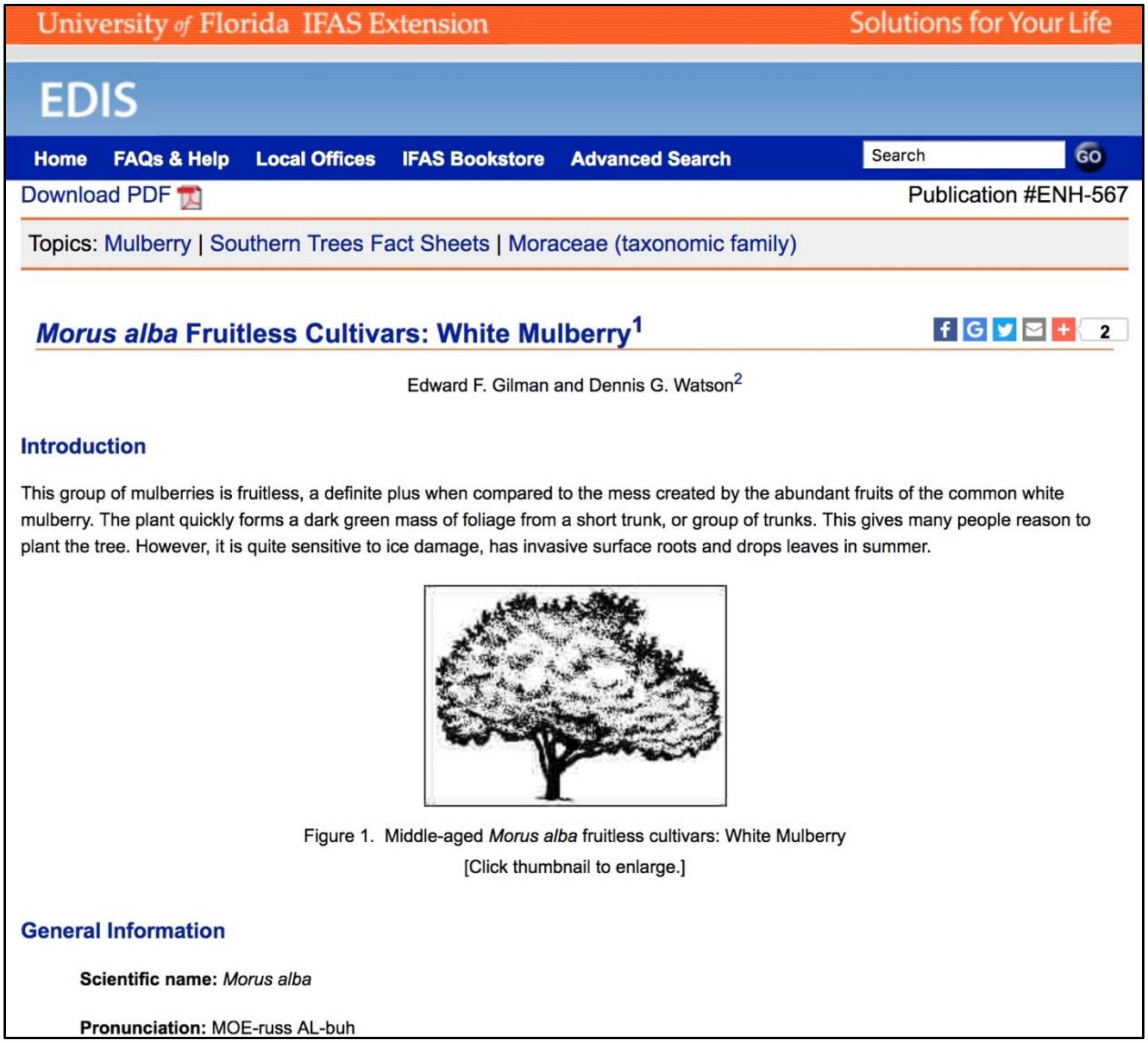
Plant Database design attempts to address incompleteness by enabling and encouraging users to contribute data that is absent. The USDA PLANTS Database does not catalog region-specific growing requirements, which participants use in both their design and maintenance of permaculture systems. The SAGE Plant Database design includes region-specific growing requirements and does so because members of the local community are able to contribute their personal experiences to the data set.

5.5.3. UF/IFAS EDIS

The EDIS publication database has over 7,000 peer reviewed publications produced by the University of Florida Institute of Food and Agriculture Sciences. The publications cover a range of topics including, adjacent to, and beyond plants, such as agriculture, community development, ecosystem restoration, consumer information, lawn and garden care, and sustainability. Many articles are about a single species of plant, where as other articles are about a broader topic and provide only a little bit of information about a plant.

Single plant publications within this database have the most similar format to the information stored of a plant in a plant database. For example, a publication about white mulberry (see Figure 5-9) has a synthesis followed by an attribute list of properties and values and a list of references (Watson 2014). Attribute properties for the white mulberry include taxonomic and distribution information, form characteristics, growing conditions, use and management summary, pests, and diseases. This list of attributes is not exactly the same for each single-plant publication but is representative of the kinds of data found in those publications.

The primary way to find information relevant to permaculture design or practices is to use the basic search function. Users can search for any keywords of their choosing from the publications, such as the scientific or common name of a plant, insect, or animal, or land feature (e.g., wetland). Users can browse articles by topic such as agriculture, community development, environment, or lawn and garden. To browse plants and plant


University of Florida IFAS Extension Solutions for Your Life

EDIS

Home FAQs & Help Local Offices IFAS Bookstore Advanced Search Search GO

Download PDF

Publication #ENH-567

Topics: Mulberry | Southern Trees Fact Sheets | Moraceae (taxonomic family)

Morus alba Fruitless Cultivars: White Mulberry[1]

2

Edward F. Gilman and Dennis G. Watson[2]

Introduction

This group of mulberries is fruitless, a definite plus when compared to the mess created by the abundant fruits of the common white mulberry. The plant quickly forms a dark green mass of foliage from a short trunk, or group of trunks. This gives many people reason to plant the tree. However, it is quite sensitive to ice damage, has invasive surface roots and drops leaves in summer.

Figure 1. Middle-aged *Morus alba* fruitless cultivars: White Mulberry

[Click thumbnail to enlarge.]

General Information

Scientific name: *Morus alba*

Pronunciation: MOE-russ AL-buh

Figure 5-9 UF/IFAS EDIS (2018) publication about white mulberry (Morus alba).

information, a user must look in many places, which can make it hard to find data. For example, the Environment root topic has Plants subtopic, the Agriculture root topic has a Crops subtopic, and the Lawn and Garden root topic has a Landscape Plants subtopic.

Although the EDIS publication database is a rich information resource, its primary limitation is the difficulty that a user has in finding the information they are looking for. For example, the EDIS does not hyperlink key terms or concepts across publications.

Figure 5-10 UF/IFAS EDIS (2018) has seven topics for browsing, and plant information can be found in each one.

When there is a plant or concept discussed in one publication that is expanded upon in another, it is up to the user to connect the information between the two. Second, because much of the data is written in a manuscript format, the user must spend time reading large chunks of text to locate the information they need or to determine that the information is not present. In contrast, with the plant information in a database format, like SAGE, users can quickly locate and sort through plant data and information.

5.5.4. ToLN Plant Information

The Tree of Life Nursery is independently owned and has been in the business of propagating California native plants for over thirty years. They also provide public education, both in the form of workshops and online reading materials. The online reading materials include 127 plant profile documents, tips for making a native garden, a calendar of when flowers bloom, a guide to planting native plants, and a list of 30 suggested starter plants.

TREE OF LIFE NURSERY
SAN JUAN CAPISTRANO
CALIFORNIA (949) 728-0685
CALIFORNIA NATIVE PLANTS

Ribes aureum, GOLDEN CURRANT

The largest grower of California native plants in the state, Tree of Life Nursery has been located on the historic Rancho Mission Viejo in San Juan Capistrano for over 20 years. Largely a wholesale nursery, the ***Roundhouse Plant Store*** is open to the public Fridays year-round and Saturdays in fall and spring. For those interested in learning more, we offer a large selection of books on the California region regarding landscaping and horticulture, natural history, conservation, and more. The nursery's catalog, "Plants of El Camino Real," is a beautifully arranged collection of information about the plants we grow, with helpful hints for landscapers and gardeners looking for the right plant for the right place. Come experience Tree of Life for yourself!

BERRY-PRODUCING SHRUBS
Arctostaphylos species
Comarostaphylos diversifolia
Heteromeles arbutifolia
Mahonia species
Prunus species
Rhamnus species
Rhus species
Ribes species
Sambucus mexicana
Symphoricarpos mollis
Vitis species (vine)

Golden Currant is a summer-deciduous, upright shrub that grows to 8 feet tall in oak and riparian woodlands and forest edges to 3000 feet. Long, arching branches and bright green leaves characterize this plant. The small, sunny yellow flowers fade to orange and are followed by a light orange berry. It makes a nice understory accent for native oaks, pines or other mature trees, a backdrop for a pond, along a creek or stream bank or in a partly shaded mixed border with *Rosa californica, Philadelphus lewisii, Leymus condensatus, Rhamnus californica, Salvia spathacea, Rhus trilobata* and *Arctostaphylos.* Plant in part shade and water once or twice a month. Golden Currant provides valuable wildlife habitat, attracting hummingbirds and butterflies to its flowers and songbirds to its juicy berries.

PLANT PROFILES   VISIT WWW.TREEOFLIFENURSERY.COM   © 2001 TREE OF LIFE NURSERY

Figure 5-11 The ToLN (2018) plant profile on the golden currant (*Ribes aureum*) provides a one paragraph summary of the plant's form, ecosystem services, companion plants, and growing conditions.

The 127 plant profiles are similar in content to the information found in a plant database. These profiles are brief, typically only single paragraphs, but include information about the plants form, their ideal growing conditions, companion plants, and ecosystem services. Sometimes, these profiles also include information about how the Native Americans used the plant.

The ToLN plant information, and particularly the plant profiles, provide visitors with a succinct set of native plant information. However, because the information is limited to native plants, users are unable to explore native plant relationships with non-native but agriculturally productive plants – a technique often used in permaculture. In contrast, the SAGE Plant Database supports this sort of exploration by featuring a range of non-native plants that are valued for their ecosystem services or human uses in addition to native plants. The ToLN plant information has similar limitations to those of the EDIS publication database in the sense that the data or information contained within those documents are not cross-referenced. Finally, the ToLN plant profiles omit pertinent details regarding the plants growing conditions, uses, or form in attempt to be brief. By filtering for specific properties, the SAGE database can provide data as brief or as extensive as the user requires.

5.5.5. Natural Capital Plant Database

The Natural Capital Plant Database is a plant database designed specifically to support practitioners engaging in permaculture projects. Staff and registered contributors provide the data through referencing scholarly resources. The plant attribute data are similar to that of SAGE, including category, characteristics, tolerances, behaviors, human uses, and ecological functions. The Natural Capital Plant Database also lists which user-polycultures a plant is a part of, associates of a plant (i.e., substitutions that fill the same niche), and compatibilities and incompatibilities with other plants.

The Natural Capital Plant Database has four membership tiers, including free and paid. Free Plant List Access allows a user to see basic plant information from plant lists and search by plant name. The Annual paid membership allows users to search the plant by site conditions, ecological functions, human uses, and limiting factors. Designer memberships are more expensive and allow users to do customized searches of the database based on their site conditions and download comma separate value (CSV) reports. Researcher membership are designer memberships with the additional allow users to supply new plant data.

There are many similarities and comparatively few differences between the SAGE Plant Database design and the Natural Capital Plant Database compared to the other databases, but two differences are significant. First, the Natural Capital Plant Database does not designate a regional context for any data, making it virtually impossible for the user to know if the data apply to their context. Second, the SAGE Plant Database is designed to be open access for searching, open-source for modifying, and contain a public API whereas the Natural Capital Plant Database requires a paid membership and does not have an open API. The SAGE Plant Database's openness will allow any community

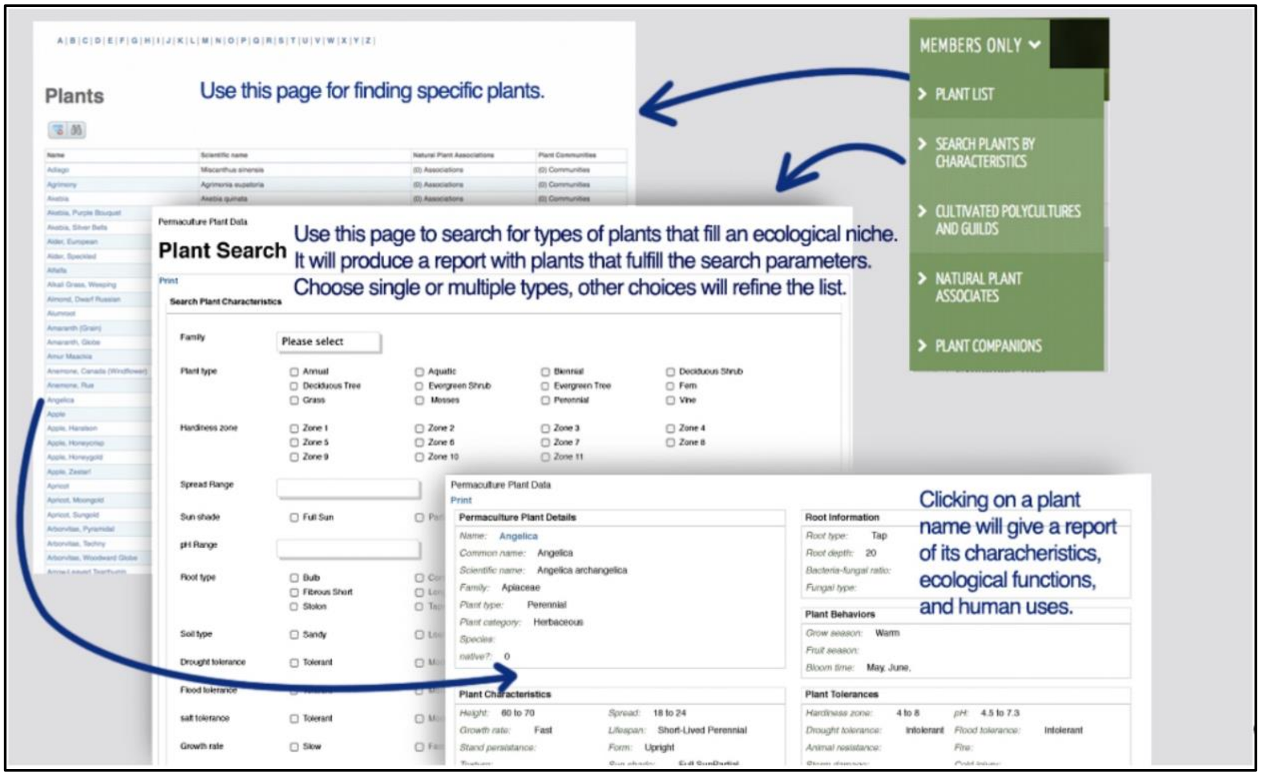


Figure 5-12 The Natural Capital Plant Database (2018) has several ways to search and view plant data depending upon a user's membership status. This composite image was created by Natural Capital and posted on their website.

with similar activities, culture, and values to clone and adapt the database to their specific needs. SAGE Plant Database's API will allow for any person to build agroecosystem design tools that can harness the plant data inside the SAGE Plant Database. These two differences, regional context and openness, warrant the need for the SAGE Plant Database in the presence of an otherwise similar tool.

5.5.6. Discussion on Human Values

Values are a person's or community's judgement of what is important in life (Friedman, Kahn, and Borning 2006). The values implicated in the design of SAGE are likely different from those of the other databases because the other databases were designed for different use contexts. However, the results from systematically comparing the values embedded in the other databases with those in SAGE Plant Database design are tenuous because I did not have full information regarding which values were implicated in the design of those artifacts.

In effort to understand the values embedded in the other databases, I employed qualitative coding and investigative techniques described in Freidman et al.'s (2006, 15–16) "practical suggestions for using value sensitive design." I mapped out stakeholders, identified benefits and harms for each stakeholder group, and mapped the benefits and harms onto corresponding "Human Values (with Ethical Import) Often Implicated in System Design" defined by Friedman, et al. (2006, 17–18) and onto the community values defined in section 4.2. I also used written statements on the websites and major design decisions of the other databases to deduce their embedded human values. The result of this effort can be found in the Appendix. Although the results of this analysis are incomplete, this section presents a few key similarities in the values of the other databases and describes how they diverge in the context of grassroots sustainable agriculture.

The broad notion of environmental sustainability is a value that each of these systems have. Conservation and/or restoration are explicit goals of CalFlora, USDA PLANTS, UF/IFAS EDIS, and ToLN. Likewise, sustainability in the context of agriculture are explicit values of EDIS and Natural Capital. Each artifact provides some information about a plant's ecological context, specifically their growth requirements. However, with the exception of the Natural Capital Plant Database, the other databases provide comparatively little (e.g., ToLN, EDIS) to no (e.g., CalFlora, USDA PLANTS) information about the supporting and regulating ecosystem services a plant provides. While the notion of environmental sustainability may be fulfilled in the other databases' intended contexts, those without sufficient information about supporting and regulating ecosystem services are less useful in the context of agroecosystem design.

Sociocultural equity is another of the participating communities' values that is also present in the information ecology each of these systems reside in. Article 25 of the Universal Declaration of Human Rights specifies, "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food..." (United Nations General Assembly, 3rd Session 1948). Catoula, representing the UN FAO, (2008, 7) argued that the right to natural resources is implicit to the right to food, "both through direct consumption and through providing the basis for income-generating activities that enable people to purchase food." Other organizations argue that environmental conservation supports "rights of people to secure their livelihood" ("Human Rights | WWF" n.d.), and that environmental health has a direct impact on human security (Valli 2004). The SAGE and other plant database information ecologies work towards supporting equitable access to food, natural resources, a healthy ecosystem, and wildlife.

Specifically, CalFlora and ToLN support access to environmental health by providing people with access to information about their local native and wild flora and the physical plants. USDA PLANTS and Natural Capital Plant Database support access to food, natural resources, and environmental health by providing people with access to information about agricultural and wild plants. EDIS supports ecosystem health via conservation and access to food by conducting research and publishing information about agriculture and ecology. ToLN, CalFlora, and EDIS also support access to food, natural resources, ecosystem health, and to nature and wildlife through education programs. Natural Capital directly supports a person's ability to use the data to grow food and other resources for themselves and their community.

In the context of progressing access to food in particular, most of the other database information ecologies are insufficient. CalFlora and ToLN outreach and education focus exclusively on native or wild-growing California plants, not including plants used for modern-day food consumption. The USDA PLANTS information ecology does not provide outreach or education programs and also does not have characteristic properties for most food producing plants. Natural Capital's shortcoming is only in that it requires users to pay for a membership – even though the fee is low, it is a great enough barrier to turn many newcomers away. EDIS does support sociocultural equality in the context of food sovereignty, providing their information for free online and through outreach programs on a range of agricultural and non-agricultural plants. The single criticism of EDIS, though, is that the information on the EDIS site is provided via academic publications, often requiring a degree of education to understand beyond what novices may have.

5.6. Implementation of the SAGE Plant Database

The design of the SAGE Plant Database presented in this chapter is available for anybody to implement for their community. Implementation details can vary, largely depending on the skillset and range of knowledge of the community's technology steward. As the technology steward for this community, I present my implementation decisions and experiences.

In effort to reduce the project into a manageable scope, and given my current physical proximity with the community, only the Manzanita community engaged in the first and current implementation cycle of this research. This section presents the front-end implementation, back-end implementation, and distribution model of the SAGE Plant Database for the Manzanita community.

Throughout this section, I introduce the members of my development team and refer to the development team as "we" when describing the implementation details. The development team consists of ten UCI undergraduate students, one of whom graduated and continued to support this project, two UCI graduate students, and myself.

5.6.1. Run-time Environment

The SAGE Plant Database is a Python3 web application built using the Django 2.0.7 framework with a PostgreSQL database hosted on a Heroku server. Python is an object-oriented programming language developed under an open-source license and the Python Software Foundation is a 501(c)(3) non-profit organization (Python Software

Foundation 2018). PostgreSQL is an open-source object-relational database system. The Django framework is an open-source Python web framework and the Django Software Foundation is a 501(c)(3) non-profit organization (The Django Foundation 2018).

John Brock, Moin Aminnaseri, and I chose to work with open-source frameworks that have a long-standing history of routine maintenance and upgrades to account for rapid technological advances in the web domain so that the communities using the SAGE Plant Database can adopt, maintain, and update the system without moving platforms for the foreseeable future. In contrast, proprietary frameworks tend to have less interoperability with other frameworks, making it more difficult to modify or create add-ons to SAGE, and tend to have associated financial expenses, for example, to use the framework or to receive tech support. Any framework that is not well established has a greater risk of being discontinued by the community or company that develops it, thus forcing SAGE to be redeveloped in a new framework.

Heroku is owned and operated by Salesforce, a for-profit organization. There are many hosting services to choose from, including ones that offer "green hosting" in the form of clean-energy powered servers. The reasons I chose Heroku to host the SAGE Plant Database website are because members of the development team were already familiar with it, it supported Django web applications and a Postgres database, supported uploads of git repositories (a version control system on GitHub, a web-based hosting service for git repositories), and provides free hosting during the four-year development phase. Heroku may also provide a form of energy savings because it shuts down our application when it is not actively used and refreshes the application once a day to reduce memory consumed by memory leaks, but I have not been able to find information indicating these actions provide energy savings. Once the SAGE Plant Database has completed development, been adopted by the community, and regularly uses bandwidth (i.e., is used by community members), transitioning to a comparatively expensive but green web-hosting service may be favored by the community.

5.6.2. Web Application

A simple visual design was favored for readability and to maintain low network usage for visual display, as more complicated interfaces often require more data usage. Kristen Segismundo, Daniel McInnis, and I developed the front-end based on the wireframes by Sahand Nayabaziz (see section 5.4.6).

When the user arrives at the website, they are presented with the home page which includes a list of summaries for all plants in the database (Figure 5-13). The summaries have an image, the plant names, and available attribute data. The top-left hand corner of the page is for navigation. The top bar is for searching, filtering, and logging in. The bottom left corner is for adding a plant. When a user clicks on an existing plant or adds a new plant, the website displays the full plant card.

The full plant card contains all attribute information available for that plant in the SAGE Plant Database (Figure 5-14, Figure 5-15, and Figure 5-16). It separates the attribute information into (intrinsic) characteristics, needs, tolerances, products, and

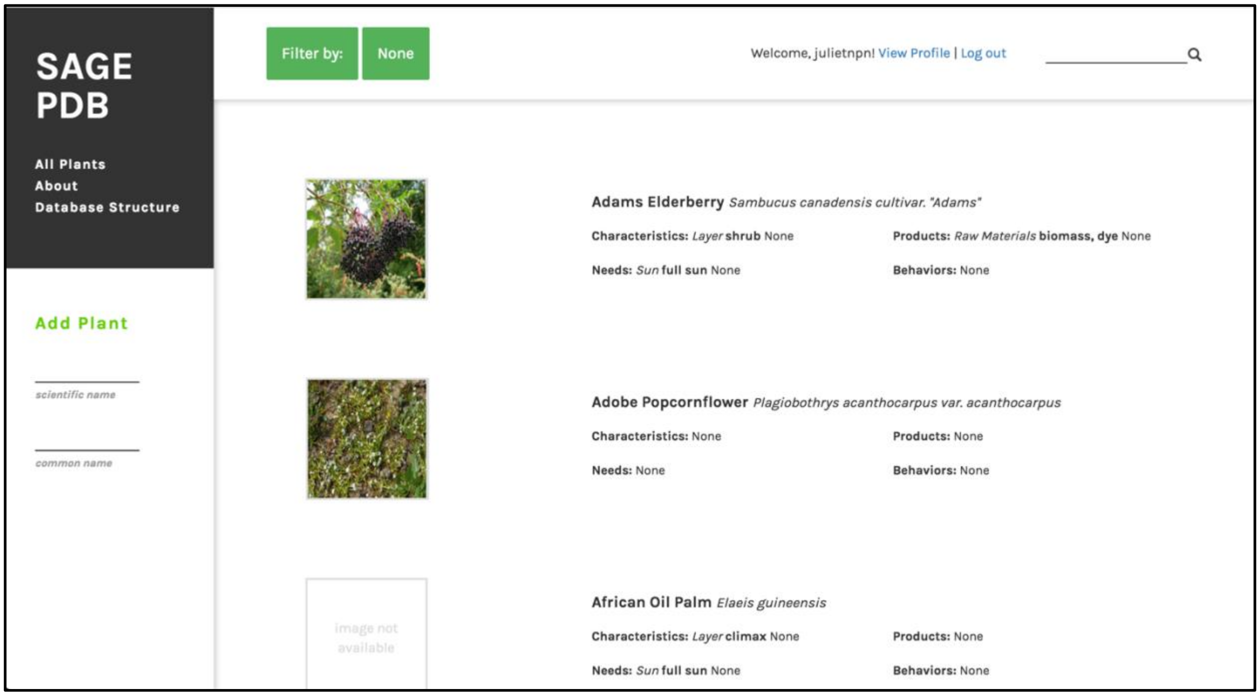


Figure 5-13 Plant database app.

behaviors. If the user is logged in, they can contribute attribute information. To modify information that has already been contributed, they click on the attribute or information (Figure 5-14). To contribute a new photo, the user can click the add photo button and search the Flickr library for images available under the creative commons license. To contribute new attribute information, the user can choose an empty attribute from the lists below (Figure 5-15). Below the plant attributes, the user can see who has contributed data to the plant and leave a comment about the plant (Figure 5-16).

A user does not need to be logged into search and download information. However, we do require users to create an account to contribute information because of the crowd-based decision-heuristics in place for quality control (see section 5.4 for more details on using a homegrown crowd for gathering data). Users can see a history of all their contributions to the database by viewing their view profile page (Figure 5-17).

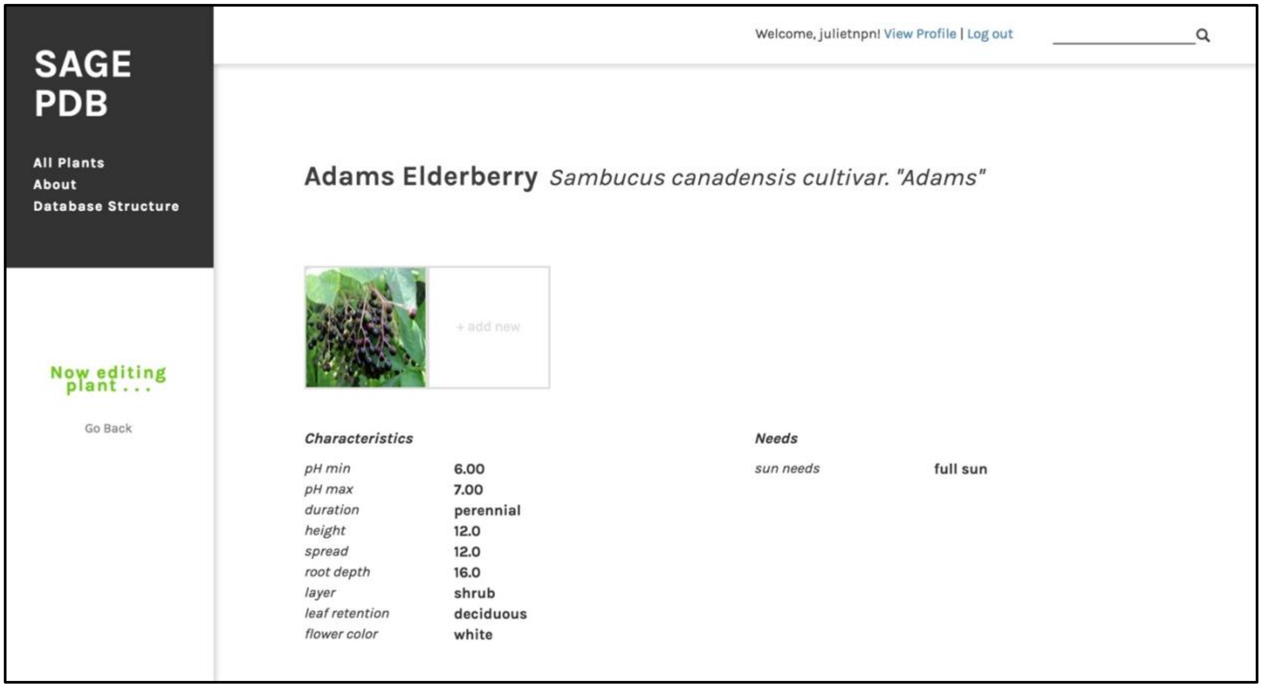


Figure 5-14 Plant card view, contributed data.

Figure 5-15 Plant card view, add new attribute data.

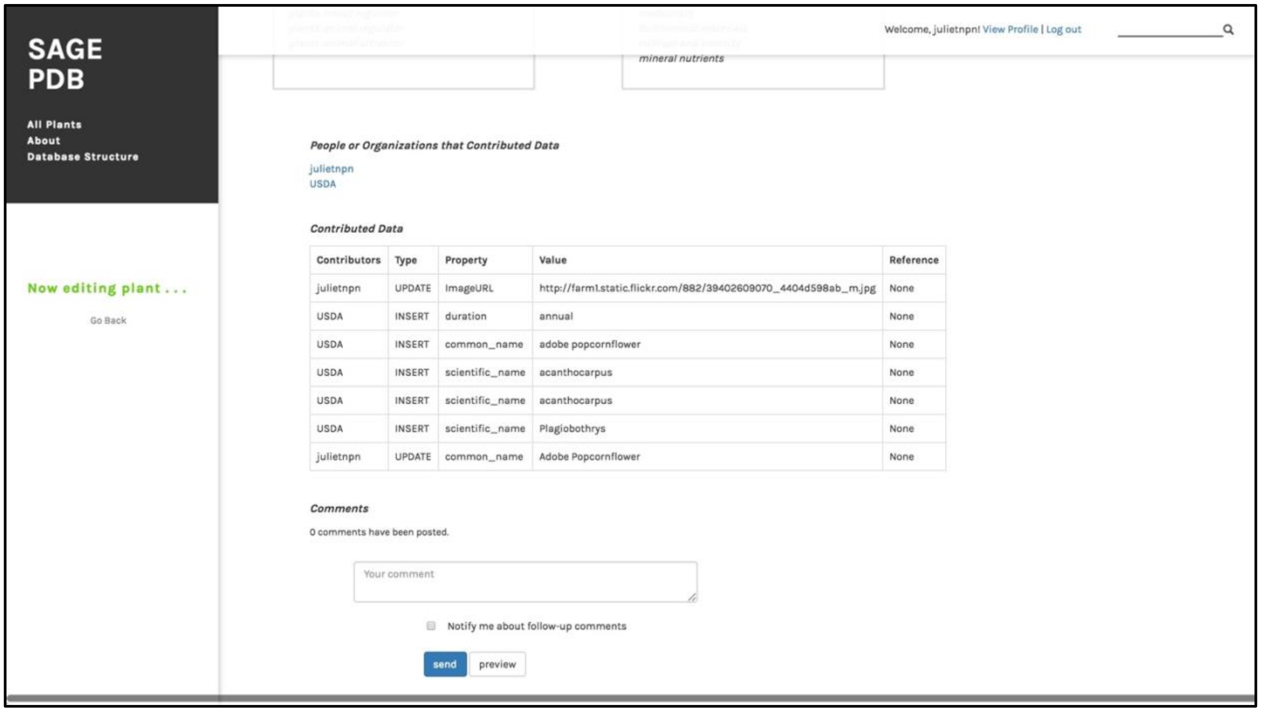


Figure 5-16 Bottom of plant card view, who contributed data, which data they contributed, and open-ended comment section.

Moin Aminnaseri and I implemented the crowd-based quality control mechanism (concept first described in section 5.4) as a weighted voting system. When a user specifies a value for a property, a vote is given to that value. If a user disagrees with a value specified in the database and change it, they will be casting a vote for a value other than the one that had the prevailing majority. At the end of each day, the database updates based on a recalculation of votes, displaying the end result in the plant card view (see Figure 5-14). If the user submits a value that is not reflected by at least the majority of previous data for this value, then the user's input is not displayed, but is recorded so it can be factored into changes made to that attribute in the future. Every change made to the database is recorded as a "transaction" and all transactions remain visible to users at the bottom of each plant page (see Figure 5-16).

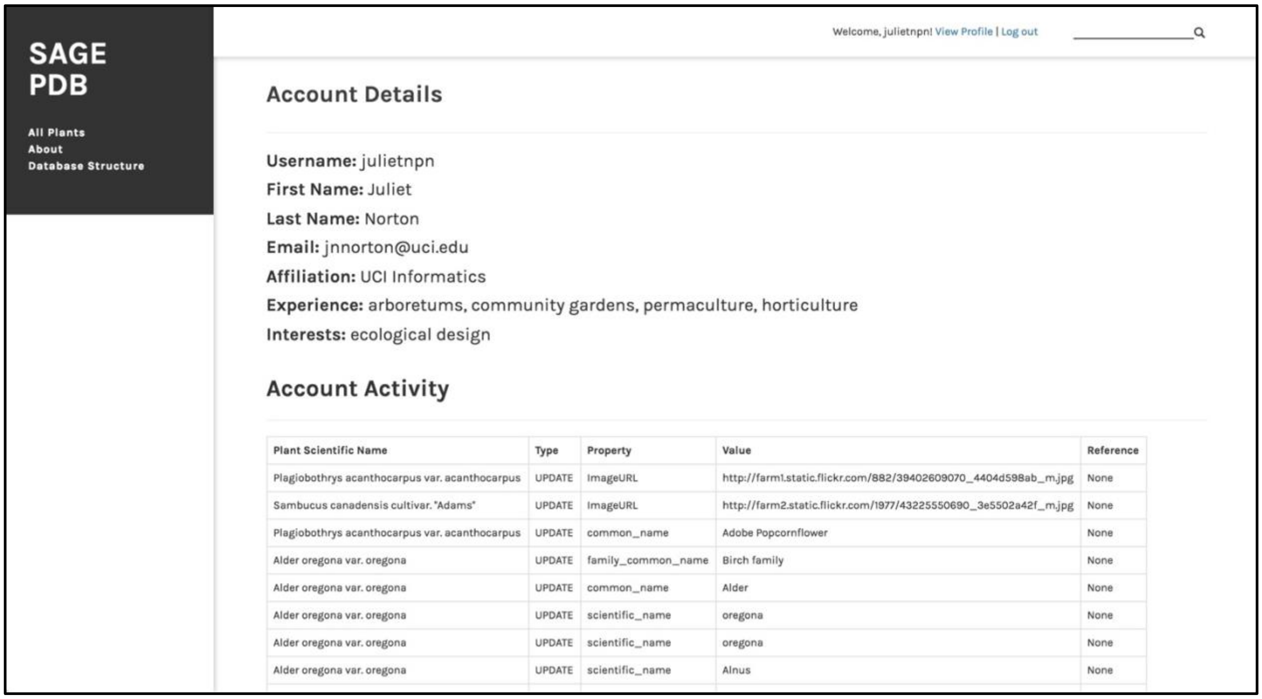


Figure 5-17 User profile and contribution history.

Matthew Nguyen and I have also implemented a comma separated value (CSV) importer so that users can import large amounts of data rather than using the graphical user interface (GUI) which can be comparatively cumbersome if the user already has their data in a spreadsheet format. To assist users in uploading data, we created a spreadsheet template that participants can use to format their data for an automatic import. Currently, users cannot yet import the data directly, but a developer is able to import this data until the feature is implemented. Moin Aminnaseri and I have also created a series of custom scripts for importing very large data sets, such as the USDA dataset, into the SAGE Plant Database.

In order to provide the large number of images needed, fellow PhD student Ankita Raturi and I co-mentored an undergraduate honors student, Xin Hu, in her creation of a stand-alone application, called “Tag Your Plants.” This application filters plant photo data from websites like Flickr and Twitter as simply searching for plant photos on websites like Flickr and Twitter results in a lot of images that are not of plants, let alone the plant the user is searching for. Xin was able to filter out the “bad data” with inclusion and exclusion tag lists so that the results are more relevant. I am currently implementing the functionality of Xin’s “Tag your plants” application into the database so that users can add photos from Flickr and Twitter without having to search through large amounts of irrelevant data.

5.6.3. Seeded Plant Data

While I have developed the SAGE Plant Database for crowd participation, the SAGE Plant Database is not yet ready for deployment for crowdsourcing input. For the initial implementation of this design, the technology steward has depended on a “test” crowd that does not overlap with the potential “homegrown” crowd so that the homegrown crowd does not fatigue during testing.

Presently the database is seeded with data for the region that the Manzanita community is located within from four sources: the USDA Plant Database, the Natural Capital Plant Database, a list created by students in a local permaculture class, and data created by three offerings of a UCI undergraduate course about global change, sustainability, and information technology. Data from these resources have been translated into our database to maintain the terminology convention I created. The data is sparse and incomplete, containing 35402 data points for 4224 plants, but serves as a starting place. Tolerance, products, and services are the least provided plant properties.

The most concerning issue with this initial population of plant data was that some of the specified uses of plants were dangerously wrong. For example, some participants stated that toxic plants were edible. It is imperative that we update the crowdsourcing methodology to prevent the occurrence of incorrect data that could lead to harmful effects. We must identify which of these data properties requires specialized knowledge and have critical impacts. Consequentially, acquiring accurate tolerance, product, and service data poses one of the most significant challenges of this research.

The next chapter reviews each of the challenges and limitations of this research that motivate my anticipated future work for the SAGE Plant Database. Before that, I review of the contributions of the research presented in this dissertation.

CHAPTER 6:

Reflections

Plant databases and information resources are prolific and varied in their structure, content, and operation. However, outside of a few fields in the plant sciences, such as plant genomics and genetics (e.g., Beavis et al. 2005; Andorf et al. 2016; Duvick et al. 2008) and functional ecology (e.g., Kattge et al. 2011; Kleyer M. et al. 2008), there is little documentation on the design rationale or development of community wide standards for plant databases (Rhee and Crosby 2005). The importance of design rationale may also be lost on the information science community. Bowker and Star (1999, 4) argued that few information scientists see classification systems, such as databases and ontologies, as "artifacts embodying moral and aesthetic choices that in turn craft people's identities, aspirations, and dignity."

Rhee and Crosby (2005, 2) argued that creating a database is a "legitimate scientific endeavor," but because it is rarely recognized as one, researchers neglect good documentation on the "rationale of the design and implementation, and community-wide standards for operation in annotation and data exchange". They further argued that researchers should share their development experiences via conferences and publications to alleviate this problem:

> "The majority of papers on databases describe mostly the content and user functionality available from the databases and their attendant query interfaces and offer little information on the design and implementation of the software. Also,

> there is no standard in making database software and schema available." (Rhee and Crosby 2005, 2)

Reports from the US National Research Council also underscore the importance of creating databases and the other tools within the envisioned SAGE suite for agricultural sustainability. The report titled *Toward Sustainable Agriculture in the 21st Century* argues that landscape-scale planning tools supported by relevant databases "could contribute to effective targeting of efforts at the farm, community, and watershed levels" (Council 2010, 529). Databases, the report argues, are a part of research platforms that "encourage and support interdisciplinary research beyond traditional biological integration to economics and social sciences" (Council 2010, 322). The report titled *Computing Research for Sustainability* argues that databases and other "fundamentals of the computer science field ... offer unique and important contributions to sustainability" (National Research Council 2012, 87). Specifically, "databases play a crucial role in the understanding of ecosystems" (National Research Council 2012, 111), from storing raw measurements of the environment to providing inputs to and recording outputs of predictive models of ecological functions. The report further explains that computing methods, such as "queryable structured data," are essential to coping with vast amounts of unstructured data that is now available within sustainability research (National Research Council 2012, 87).

Though this dissertation ends with the initial implementation of the SAGE Plant Database, it primarily demonstrates the stakeholders' practices, values, and information needs, the database design, and the need for such a system in the presence of other databases. In the next section, I review the distinct contributions of this research to the scientific community and the participating sustainable agriculture communities. Then I summarize the issues encountered in this research and limitations of this work. Finally, I present a roadmap for future work on SAGE.

6.1. Summary of Contributions

This dissertation set out to understand the information needs and practices of sustainable agriculture communities and sought to demonstrate how to involve sustainable agriculture communities in the development of information technologies for their practice. Through this process I became intimately familiar with the practices of two sustainable agriculture communities. I presented their practices throughout the dissertation, from Prologue to the Comparative Analysis (section 5.5). These observational accounts are themselves a significant contribution to research, as so few formal inquiries into permaculture communities exist (Ferguson 2017; McCune et al. 2017). In addition to this inherent contribution, there are six distinct contributions, for both research and grassroots sustainable agriculture more broadly, that I would like to call special attention to: (1) definition of information challenges and (2) community values; (3) the formation of goals, requirements, domain knowledge and design of the SAGE Plant Database; (4) grounded development of a plant ontology for agroecosystems; (5) a comparative analysis of databases used by and designed for the communities; and (6) an implementation of the

SAGE Plant Database. The definition of information challenges and community values, and the formation of goals, requirements, and domain knowledge contribute to an understanding of an under-explored set users in the HCI domain. The design and implementation of the database contributes to knowledge about systems, tools, architectures and infrastructure at the intersection of agriculture and HCI domains. The grounded development of the plant ontology contributes a high-level model to the agriculture domain that can support the education of newcomers to sustainable polyculture design. The comparative analysis contributes to the development and refinement of plant database artifacts and interaction techniques for sustainable polyculture design. This section reviews each of the six contributions in detail.

Information Challenges. The first distinct contribution of this research was the set of information challenges I observed across both communities:

- Participants had difficulty determining what information should come from the client;
- Participants lacked site-specific environmental data required for sustainable polyculture design;
- Participants had difficulty organizing and visualizing complex relationships among design elements and between design elements and the surrounding environment;
- Participants lacked region-specific plant lists for sustainable polyculture design.

These information challenges represent opportunities to design systems that address issues of complexity in the sustainable polyculture design process specifically and the agroecosystem design process broadly. Knowing that these challenges exist within the two participating communities, researchers can explore if the same challenges in other permaculture communities or in the agroecology community. The participating communities can also use this information to evolve education style, curriculum, and tools (including tools independent from this research). If farmers diving into agroecology experience similar information challenges, then the SAGE Plant Database and other systems envisioned in the Prologue and described in the Future Work have the potential to support those communities.

Values. During the course of my fieldwork, I observed the manifestation of the core permaculture values and discovered three additional sets of values that have implications for the sociotechnical systems designed for these communities.

- Core Permaculture Values
  - Earth Care, People Care, Fair Share
- Resistance Values
  - Quotidian Insubordination, Empowerment
- Technology Values
  - Selective Use, Modularity and Multiplicity, Longevity
- Long-term Values
  - Food Sovereignty, Regeneration, Sociocultural Equality

With the SAGE Plant Database, I provide a single instantiation of how these values could be incorporated into system design. However, as an intermediary finding, these values are important because they could be interpreted and incorporated into many different sociotechnical systems in many different ways. Many of these values are underexplored in HCI, yet other communities have overlapping value sets (e.g., survivalists, people who engage in simple-living, intentional communities, and some religious or spiritual communities).

However, sustainability is the overtone of these values, and sustainability is well explored in HCI. In context of DiSalvo, Senger, and Brynjarsdóttir's (2010) axes of differences of S-HCI research, my research considers sustainability as both a research focus – I incorporated the values of sustainability into the information systems – and application area – I supported the work of sustainable agriculturalists. Continuing with their axes, this research situated users as individual activists bound by a community and cause, aimed to solve the users' problems rather than framing the user as a problem, supported the fundamental change of user lifestyles, and grappled with the inadequacies of technology as a solution to their problems, including the "wasteful rapid obsolescence cycle of IT products." In context of Knowels' et al. (2013) themes for motivating questions in S-HCI research, my research explored the role of technology in making society sustainable and promoting less destructive and more satisfying patterns of consumption.

This value set is an opportunity for reflection and evolution for the participating community with an opportunity to reflect and evolve on. As the communities build tools, incorporate new practices, and forge new collaborations, the value set can be used as an evaluation tool for making decisions and designs.

Goals, Requirements, Domain Knowledge, and Design. The outcomes of the requirements analysis are another intermediary contribution of this research that informed the design of the SAGE Plant Database. The goals and requirements presented in section 5.2 demonstrated the need for distinct information systems for communities with a value set and practice same as the communities that participated in this research. The goals for designing the SAGE Plant Database were:

- Goals
  - Represents and informs community plant knowledge
  - Maintains high quality data
  - Supports social learning
  - Supports quotidian insubordination
  - Supports evolving community needs
  - Supports anti-consumerism
  - Supports long-term equality
  - Supports environmental sustainability

The design of SAGE Plant Database takes steps towards supporting each of these goals. While we are still in the early stages of populating the database and have uncovered challenges, these goals have productively informed the definition of quality requirements:

- Quality requirements
  - Availability - online and offline, export and import data
  - Integrity – data is accurate and authentic
  - Confidentiality – anonymous interaction unless identifying information is authorized for public viewing
  - Sustainability – minimize ecological footprint
  - Interoperability – able to work with other systems that can, for example, recommend companion plants
  - Reusability (Open-source) – all or parts of system can be repurposed for new or different systems

The quality requirements guided foundational decisions about the implementation of the SAGE Plant Database, such the use of open source frameworks like Django, Python 3, and PostgreSQL in the creation of our open source framework. Furthermore, the quality requirements Furthermore, the quality requirements guided the specification of high-level functional requirements that were essential to engaging in the first round of design and implementation:

- Functional requirements
  - Provides users with the ability to search and organize data
  - Provides users with ability to add or modify data
  - Provides users with ability to save data
  - Provides a platform for sharing planting, growing, harvesting, and use techniques
  - Provides an API to support future community-designed applications requiring plant data
  - Operates on a range of personal computing devices (old and new, mobile and desktop)

The domain knowledge presented in section 5.3 detailed exactly which kind of plants are included in their design and the plant attributes that are considered in design decisions:

- Inclusion Properties
  - Climate appropriate
  - Provides ecosystem services that appeal to humans
  - Provides ecosystem services that support the local ecology
  - Low maintenance
- Plant Attributes
  - Products and services
  - Growing conditions
  - Intrinsic characteristics

I uncovered a set of design challenges (see section 5.4.1) and addressed them based on my engagement with the communities and their practices. The following set of design challenges are grounded in the translation of the domain knowledge of sustainable polyculture designers to database technology and are irrespective of community culture and values therefore applicable to any permaculture community:

- Level of detail for plant entry
- Portrayal of plant information and relationships
- Representing environmental context

The design process also addressed a series of technology adoption challenges (see section 5.4.3). The following technology adoption challenges would apply to any information system developed for the participating communities:

- Reverse Adaptation
- Fragile Engagement
- Obsolescence
- Loss of Incentive

To address fragile engagement and loss of incentive, I proposed introducing two non-IT entities to the information ecology: a technology steward and a homegrown crowd (see sections 5.4.4 and 5.4.5). The technology steward is both a member of the community and the development team. The steward recruits participants to the homegrown crowd and deploys the technology with training seminars. The homegrown crowd is a collection of members of the community that participate in the aggregation and building of knowledge. I argued that if members of the community put forth the effort to create the information in the system so it can be used by themselves and their community, then they will have an inherent incentive to continue to contribute and use the system.

The design can be implemented by any person to support their community. Within permaculture and other communities with similar values and practices, this design is largely applicable independent of the specific type of surroundings or the climate or any other characteristics of the application domain, and, because it is open technology, can be modified to accommodate the exceptions.

Plant Ontology for Agroecosystems. The plant ontology (presented in section 5.4.1) underlying the SAGE Plant Database design is a significant contribution to research. It demonstrates the relationships between plants in an agroecosystem context and at a high-enough level of detail that farmers and gardeners can comprehend and utilize in their practices. This plant ontology, however, is likely not appropriate for scientific research in agroecology or functional plant ecology as it makes abstract representations of extremely complex relationships.

This plant ontology can be used as an education and design tool within the participating communities. For example, this ontology can be used to help newcomers to sustainable polyculture design understand which relationships among plants are important to support and the number of relationships among two kinds of plants. The abstract nature of information also makes it helpful for people to spatially plan annual gardens and beds. A person can use the information for height, spread, time to maturity, time to first harvest, and so on to determine how close or far plants can be placed to each other and time when they should be planted so the harvesting of one kind of plant, such as potatoes, doesn't disturb the growth of another nearby plant that is not yet ready for harvest.

Comparative Analysis. The comparative analysis (presented in section 5.5) demonstrated the need for the SAGE Plant Database by determining the following limitations of other kinds of plant data services in the agroecology context (see Table 13). The comparative analysis also provides the community with a roadmap of which kind of information these data services have and how they are relevant to sustainable polyculture design.

Implementation of the SAGE Plant Database. The source code for the current implementation can be found on GitHub (https://github.com/julietnpn/sage/). This early, in-progress implementation (presented in section 5.6) serves as a proof-of-concept for the design of the SAGE Plant Database. Seeding the database with plant data provided a first-wave evaluation of the crowd mechanisms, particularly in context of the quality and kinds of data we can expect to receive. We can expect a wide variance in organization, terms, and quality of the data. The community can use this implementation to organize and think about their use and contextualization of plant data.

6.2. Difficulties and Limitations

Technology Stewards. Neither the Live Oak nor the Manzanita communities had technology stewards before this work, and I was asked to provide technological solutions for both communities. While I've been a technology steward to both communities, perhaps the largest risk of this research is that the next technology steward, if there is one, may not desire or have the financial support to continue this work once I am gone. Silberman (2015a) encountered a similar risk upon the conclusion of his doctoral research in which his construction and maintenance of a web-tool that allowed Amazon Turk crowd workers to review and discuss their employers. He argued that his tool is unlikely to receive research funding or financial support from the users of the tool. He concluded that support from direct stakeholders, donors among the general public, and nonprofit funding institutions were the "most likely possibility for securing dedicated staff for... maintenance and evolution" (Silberman 2015b, 152). I too suspect that the stakeholders and funding institutions associated with the community will need to be the primary source of financial and personnel support if the SAGE project is to persist in the Live Oak and Manzanita communities.

Homegrown Crowd and Data. The participating communities had many transient members and there were comparatively few experts to a growing sea of novices. Experts in the communities were often over-subscribed to their own work, indicating they would have little time to support a community plant database project despite believing the tool would be a boon to the maturation of the community practices. Moving forward, this research will face challenges of eliciting participation of and the knowledge from expert community members.

The lack of representation and input from expert community members can lead to incorrect and sparse data in the SAGE Plant Database. A predominately novice crowd may produce more incorrect data than the experts within the community are able to identify. As discussed in section 5.6.3, incorrect data can lead to detrimental effects such as users believing a toxic plant is edible. Furthermore, if the crowd is largely comprised of novices, most of the data in the database is likely to be derived from reference materials, such as instructor plant lists, books, or online plant information resources. This phenomenon could lead to a relatively sparse database because most of the novices are not skilled to fill the gaps in existing knowledge. Moving forward, this research will also face challenges of educating novices in the formation of new knowledge and assessment of accuracy of knowledge found in reference materials.

Activist Research in Academia. Activist research supports communities in their process of pursuing some form of social change that equalizes the status quo in a way the group believes is necessary. However, because activist and academic goals do not usually align, successful activists tend to have strained relationships with academia and successful academics have difficulty developing strong ties with activist communities (Cancian 1993). I too found challenges in striking this balance. As an activist with a long-term commitment to the communities, I built trust and familiarity that made doing research possible. For example, note taking in a learning environment is not invasive, but I needed to build trust before community members felt comfortable enough to engage in interviews. However, activist research requires participation of the communities in as much of the research as possible (Cancian 1993). Despite the communities' ongoing interest in my research, there were occasions when I could not elicit their participation in requirements gathering exercises. Fortunately, the personal relationships I formed allowed us to engage in spontaneous conversations about the research and gain their opinions of participating in the research informally. Also, my insider perspective afforded me a deep contextual understanding of the communities' goals in context of this research.

Activist research can require a long time for collecting and analyzing data, and even longer to publish. This is a conflict between activist research and academic success that many activist scholars have observed and experienced (Cancian 1993). In essence, activist researchers faces dual accountability: researchers "must hold their work accountable to both activist and academic standards" (Cancian 1993). Often, those we study have long forgotten we studied them or why by the time we're ready to share our findings. Others don't forget and wonder if their time was ever worth it. What are they getting in return? Like true activists, these participants want to make change that is timely and meaningful. Sometimes, to the sustainability activist, the research findings are neither timely nor meaningful. As a result, we want to be sure to support our participants in ways other than our research. Volunteering time to plant a garden, tabling at an event, or sharing skills in return are practical ways to support our sustainability activist participants. For example, I maintained a website for the Live Oak Permaculture group. Along this same vein, I encourage sustainability activism researchers and designers to aim to make an impact in the community they are working with. After becoming well established in the Manzanita Permaculture community, I hosted local workshops that not only informed this research, but also offered learning opportunities to the communities and build a permaculture demonstration site.

Comparative Methods. The systematic comparative analysis presented in section 5.5 demonstrates the need for a plant database and ontology that supports sustainable polyculture design. However, I was unable to perform a systematic comparative analysis on the values that underlay the other plant databases. While my attempt at performing an analysis with information only publicly available on the other database websites and associated publications led to informative results, these results are incomplete without investigative interviews of the designers and development teams to determine a complete set of the values embedded in those systems. Like the SAGE Plant Database, the other databases likely have ethical values that are not publicly stated.

Studying Pseudoscience. Permaculture is a non-scientific endeavor into agriculture. Critics have called permaculture a pseudoscience (R. Scott 2010; Chalker-Scott 2010) and practitioners defend its legitimacy as a design methodology. Rafter Sass Ferguson, a researcher who participates in both permaculture and agroecology, argues that upon analyzing the defining characteristics of a pseudoscience, surely some will ring true to permaculture for most practitioners (Ferguson 2014b). Respecting permaculture's move away from academia when "science wasn't ready," Ferguson (2014b, 1–2) argued that permaculture should return to the sciences as a "people's science" because the ongoing pseudoscience style of thinking can "handicap" the movement from achieving its goals.

In my time working with the permaculture community, not only did I observe the effects of pseudoscience on their practice and education, but it impacted the project I was working on. Specifically, members of the communities followed no systematic organization of plants, conceptualized functions of plants that do not actually exist, such as dynamic accumulation, often conflated species or varieties of plants, and had the mentality that detailed ecosystem behaviors would almost magically form if they organized beneficial relationships on a macro-level. Ferguson (2014b, 2–3) observed a similar phenomenon and told the permaculture community, “Our literature shows that we have a weakness for extrapolating from ecological principles in a way that severely oversimplifies the processes at work.”

To this extent, the data from participants in these communities may be riddled with misconceptions, and those misconceptions, if not caught and handled by an expert, will continue to propagate throughout the community. In the later stages of this project, I have come to understand that the communities may also need a Science and Research Steward – a member of the information ecology that can guide their community on refuting inaccurate claims and investigating new or unstudied ideas.

Another problematic state of affairs within permaculture, according to Ferguson (2014b, 2), is the “diversity of styles and practices with which people promote and defend permaculture.” Although a diversity of practices can lead to innovative discoveries, in the context of how plants are represented for sustainable polyculture design, the lack of a consistent ontology makes it difficult to build and share education and design resources. As a result, the plant ontology for the SAGE Plant Database has to be open for changes particularly in the early stages of deployment.

The plant ontology is designed to support the participating permaculture practitioners, which largely involves high-level design based on prior experiences or examples and experimentation. The ontology as it stands likely falls short in supporting systematic polyculture design, in which support species are supported by other species towards achieving an ecosystem-like behavior, because it was grounded in the practice of the participating communities. My intention is, however, that the SAGE Plant Database and its underlying ontology can help establish a sense of scientific progress regarding sustainable polyculture design in the permaculture context.

6.3. Future Work

Agroecology and Permaculture are two interpretations of sustainable agriculture. As Warner (2007, 28) points out, “agroecology is becoming a primary scientific paradigm to guide alternative agriculture, partially replacing the term “sustainable agriculture” within the academy.” Similarly, permaculture appears to be partially replacing the term “sustainable agriculture” within North American grassroots activist communities. If members of the permaculture movement take measures to diversify and adopt a people’s science practice, permaculture has the ability to stimulate and strengthen the global social movement towards sustainable agriculture.

This research is an initiative to propel permaculture towards a people’s science, and the contributions of this research are the initial steps. However, for this research to make a long-term and widespread impact, there are several ways in which this research needs to be continued. First, I present updates that need to be made to the SAGE Plant Database implementation. Second, I present the concepts for the other applications in the Software for AGricultural Ecosystems (SAGE) suite. Finally, I present plans to apply this work beyond the permaculture context.

Implementation Updates and Deployment. I am furthering my implementation of the SAGE Plant Database Design. Anyone wishing to keep track of the implementation status of the SAGE Plant Database can visit the issues list on the project's public GitHub page (https://github.com/julietnpn/sage/issues). Aside from development tasks (e.g., design iterations and programming), one of my major implementation tasks is to move the project to a green hosting service. However, to accomplish this I must secure funding to support this more expensive service.

Regarding deployment, I aim to establish the homegrown crowd. I will personally recruit a few participants as the core of the crowd and accompany each during their initial exposure to the database. Resuming our role as the technology stewards, my team and I will guide them in assuming a contributor role of importing their personal data sets, then teach them how to search the database, add new data, and visualize the overall contents of the database for the purpose of sustainable polyculture design. Once all members of the initial crowd have gone through this process, the technology stewards will assess the need for another development iteration and test again with a small crowd if necessary. Because we have been testing this process with non-community members in an effort to avoid fragile engagement, we hope to reduce the number of necessary early design and implementation cycles. Finally, we will introduce the database to the entire information ecology, and at this point I hope to explore novel recruitment and knowledge elicitation techniques and dispatching mechanisms. As conflicts and repeated search-misses generate queries, we will monitor the dispatching mechanisms success and failures in assessing response time and frequency to improve the number and kinds of requests for each crowd member.

SAGE Envisioned. The SAGE suite presented in the Prologue is what I aimed to begin building with this research. The entire SAGE suite could at least include a plant database, a sustainable polyculture design tool, a forum, a plant photo browser, an environmental factor database, and a community agroecosystem coordinator. Here I provide a brief description of each of the envisioned applications in the SAGE suite.

Plant Database. The region-specific plant database is both a stand-alone information tool and a foundational component of the design tools in SAGE. As a stand-alone tool, it will have a comprehensive search and filter feature, data credibility system, and discussion board. The data for this database is provided by a homegrown crowd consisting of members of the local sustainable agriculture community. This is the system developed in this dissertation.

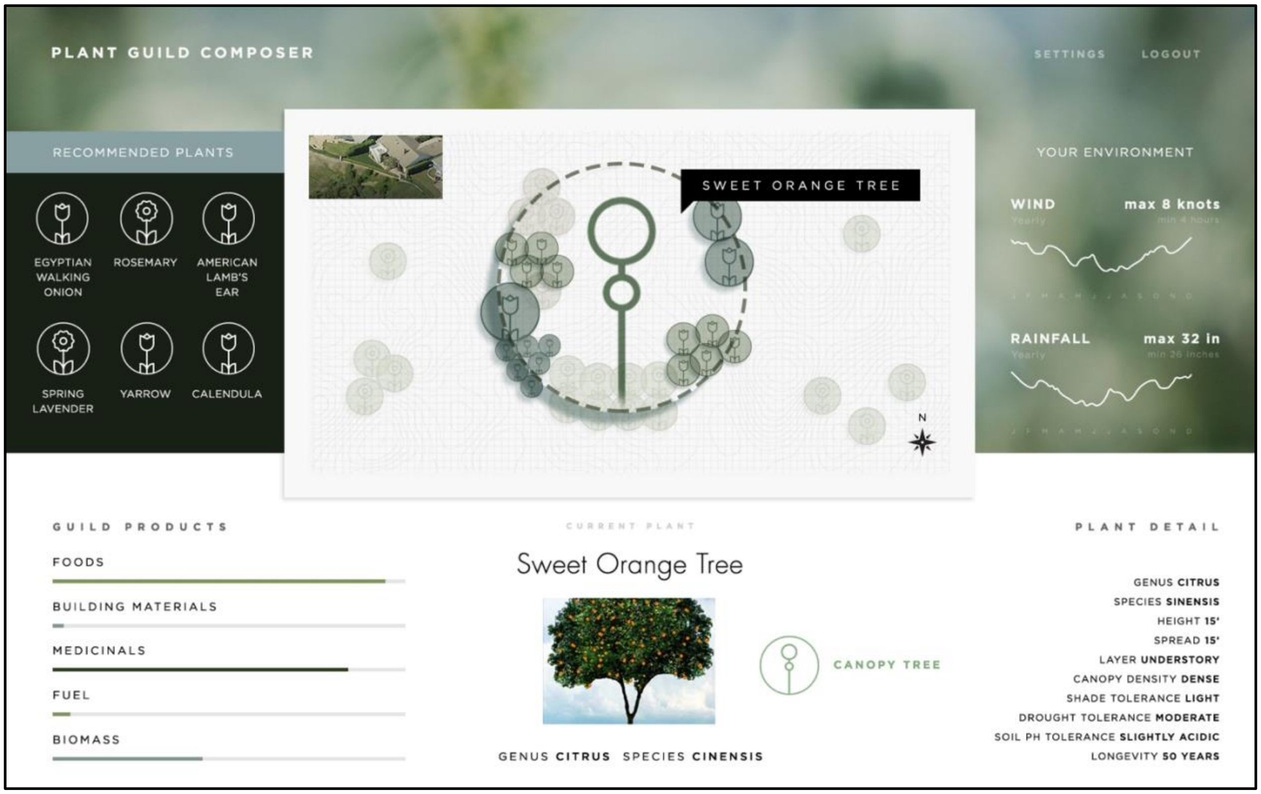


Figure 6-1 Sustainable Polyculture Composer.

Sustainable Polyculture Composer. The Sustainable Polyculture Composer is a design tool built on the plant database and the environmental factor database. It pulls local environmental data from public resources to seed the design context. It recommends plants based on environmental conditions and other user specifications. It provides a canvas for laying out plants. It incorporates a plant relationship visualization and suggest plants to fill voids in critical ecosystem roles. I have implemented a proof of concept of this tool (Norton et al. 2014) and aim to revisit its full development after the plant database has sufficient data.

Forum. The forum is be a discussion platform integrated into all of the SAGE web applications. The forum extends the physical community building experience by allowing users to connect with other members of their local community, either by providing or receiving online help to their peers. In the forum, users build credibility that helps weigh trustworthiness of the data they provide in the Plant Database or feedback they give their peers regarding sustainable polyculture design, among other relevant topics in the community. Finally, the forum is a way for the technology stewards and the other community members to maintain open channels of communication. Development on the forum has begun, and the Plant Database has a discussion component of the forum implemented at the bottom of each plant page. However, there are no reputation mechanisms in place at this time.

Plant Photo Browser. The Plant Photo Browser application routinely scrapes social media sites for images of plants in the Plant Database, filters out images that are not of the intended plant, and, if permissible, stores those images in a media asset storage system for SAGE. Users can view these plant photos either through the Plant Database application or through the stand-alone Plant Photo Browser application. The photo browser incorporates open-source plant identification systems. Such aids allow users to look up photos of a plant via the properties of the plant (i.e., flower color, leaf shape, etc.) or by taking a photo of the plant. I co-advised an intern on her development of a proof of concept for the Plant Photo Browser in 2016. The Plant Photo Browser is a high priority for implementation as an add-on to the Plant Database.

Environmental Factor Database. The region-specific environmental factor database is both a stand-alone information tool and a foundational component of the design tools in SAGE. It is built upon the same infrastructure as the plant database, including the comprehensive search and filter feature, data credibility system, and discussion board. Hand-collected data specified in the Sustainable Polyculture Composer is automatically added to this database. I have not created a proof of concept for this application.

Community Agroecosystem Coordinator. The Community Agroecosystem Coordinator coordinates the design of sustainable polycultures and other infrastructures within neighborhoods to form agroecosystems. It facilitates users' coordination in space, in time, and many different processes such as pollination. Some plants need nearby plants of the same species for wind (i.e., anemophily) or animal pollination (i.e., zoophily). It also helps communities form strategies that rely on and encourage local food system production capacity, resilience, and satisfaction of food needs and preferences. With the Community Agroecosystem Coordinator, users can make their outputs available for trade, purchase, or other transactional means. I have not attempted a proof of concept for this application at this time.

Broader Applications. This work demonstrates a set of methods that can help information technology designers understand and incorporate any grassroots sustainable agriculture community's practices and values in their design of systems for that community. While I am excited by the ongoing efforts to understand other grassroots sustainable agriculture communities across the world, such as (McCune et al. 2017), the broader continuation of this work I seek most immediately is within the North American food system.

Upon completion of this dissertation, I look forward to working with members of the open agriculture technology community to further develop the activist research methods I used in this research, apply those methods to new contexts, and participate in the formation of a comprehensive plant ontology and interoperable open plant data services.

6.4. Conclusion

The permaculture communities I studied, while well intentioned, face significant issues regarding making a meaningful impact on sustainable agriculture and sustainability more broadly. These communities and ones like it can overcome those challenges, and information technology that supports scientific engagement is well-suited to help do so. However, developing software with a grassroots activist community is hard because most people are not engaging in the community full-time (i.e., they have full-time jobs doing something else) and the others are deeply engaged in their own initiatives. Developing software with a grassroots activist community is also difficult accomplish as an activist research objective because activist goals do not usually align with the academic goals. Even so, engaging in such an objective may be best attempted in academia. Academia provided invaluable consulting opportunities with scientific collaborators that helped debunk or support claims and provide guidance in ways to make sustainable polyculture design and community activism more effective. Furthermore, the greater academic institution has provided several funding opportunities for this research.

Permaculture, and agroecology broadly, needs a plant ontology suitable to their practice, and the SAGE Plant Ontology is the beginning of that exploration. Furthermore, this project has revealed the need for novel avenues of research particularly in regard to scientific research education in activist communities. Being a technology steward has been hard – it is a full-time job that requires people skills, design skills, and technological development skills. In effect, it requires the skill set I've developed over ten years of graduate level education. These communities not only need to adopt more scientific education to facilitate the formation of permaculture researchers, but also research and technology education to foster the formation of healthy and effective information ecologies. Similarly, this research discovered the opportunity to explore how to effectively create and utilize a homegrown crowd. The communities and other resources hold significant amounts of agroecological knowledge, and we need to learn how to draw that knowledge from those resources in novel ways. By engaging in this research and presenting opportunities to continue it in the future, I seek to transform the technology-supported food system into one that furthers food security, food sovereignty, and holistic sustainability.

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APPENDIX: COMPARATIVE ANALYSIS DATA

Table 14 Comparative analysis of plant attributes in plant databases (document databases not included)

Comparative Analysis of Plant Attributes in Plant Databases (Document Databases Not Included)

SAGE	USDA	Natural Capital	CalFlora
Family	PLANTS Floristic Area or Not	Common name	Scientific name
Family Common Name	State and Province	Scientific name	Common name
Genus	County Distribution	Family	family
Species	Category	species	genus
Variety	Symbol	Plant Type (e.g., grass)	parent record
Common Name	Scientific Name	Native to North America?	wetlands
Endemic Status	Author	Plant Category (e.g., herbaceous)	toxicity
Duration	National Common Name	height	Name status
height at maturity	Genus	spread	elevation
spread at maturity	Family	growth rate	precipitation
pH	Family Symbol	life span	wet season
layer	Family Common Name	stand persistence	temp range
canopy density	Order	form	December low
active growth period	Subclass	texture	July high
harvest period	Class	sun	accumulated temperature
leaf retention	Subdivision	soil type	growing season

flower color	Division	soil moisture	hardiness zone
foliage color	Superdivision	minimum root depth	soil pH
fruit color	Subkingdom	root type	soil max salinity
root depth	Kingdom	bacteria-fungal ratio	soil min depth
degree of serotiny	ITIS TSN	fungal types	soil textures
time to first harvest	Duration	seasonal interest	soil max CaCO3
life span	Growth Habit	notes	distribution by county
shade tolerance	Native Status	fruit type	bloom period
salt tolerance	Federal Noxious Status	flower color	beneficial animals
flood tolerance	Federal Noxious Common Name	USDA Hardiness Zone	pests
drought tolerance	State Noxious Status	Soil pH	
humidity tolerance	State Noxious Common Name	Drought	
wind tolerance	PLANTS Invasive Status	Flood	
fire tolerance	Federal T/E Status	Salt	
minimum temperature tolerance	Federal T/E Common Name	Soil Compaction	
heat tolerance	State T/E Status	Mowing	
nutrient requirements	State T/E Common Name	Fire Damage	
water needs	National Wetland Indicator Status	Cold Injury	
inoculant	Regional Wetland Indicator (Region)	Wind Storm Damage	
sun	Regional Wetland Indicator (Status)	Disease Issues	
serotiny	Image Gallery	Insect/Pest Damage	

chill hours	Fact Sheets	Animal Damage
pollinators	Plant Guides	Growing Season
co-pollinating plants	Active Growth Period	Bloom Time
pruning	After Harvest Regrowth Rate	Fruit Time
trellising	Bloat	
human food	C:N Ratio	
raw materials	Coppice Potential	
medicinal	Fall Conspicuous	
biochemical material	Fire Resistance	
cultural and amenity	Flower Color	
mineral nutrients	Flower Conspicuous	
animal food	Foliage Color	
allelochemicals	Foliage Porosity Summer	
animal habitat	Foliage Porosity Winter	
erosion control	Foliage Texture	
insect attractor	Fruit/Seed Color	
insect regulator	Fruit/Seed Conspicuous	
animal regulator	Growth Form	
animal attraction	Growth Rate	
human and livestock toxicity	Height at Base Age, Maximum	
barrier	Height at Maturity	
bioremediation	Known Allelopath	
nitrogen fixation	Leaf Retention	
trellising structure	Lifespan	
shade	Low Growing Grass	

Nitrogen Fixation
Resprout Ability
Shape and Orientation
Toxicity
Adapted to Coarse Textured Soils
Adapted to Medium Textured Soils
Adapted to Fine Textured Soils
Anaerobic Tolerance
CaCO3 Tolerance
Cold Stratification Required
Drought Tolerance
Fertility Requirement
Fire Tolerance
Frost Free Days, Minimum
Hedge Tolerance
Moisture Use
pH, Minimum
pH, Maximum
Planting Density per Acre, Minimum
Planting Density per Acre, Maximum
Precipitation, Minimum

Precipitation, Maximum
Root Depth, Minimum
Salinity Tolerance
Shade Tolerance
Temperature, Minimum (°F)
Bloom Period
Commercial Availability
Fruit/Seed Abundance
Fruit/Seed Period Begin
Fruit/Seed Period End
Fruit/Seed Persistence
Propagated by Bare Root
Propagated by Bulbs
Propagated by Container
Propagated by Corms
Propagated by Cuttings
Propagated by Seed
Propagated by Sod
Propagated by Sprigs
Propagated by Tubers
Seed per Pound
Seed Spread Rate
Seedling Vigor
Small Grain
Vegetative Spread Rate

Berry/Nut/Seed Product
Christmas Tree Product
Fodder Product
Fuelwood Product
Lumber Product
Naval Store Product
Nursery Stock Product
Palatable Browse Animal
Palatable Graze Animal
Palatable Human
Post Product
Protein Potential
Pulpwood Product
Veneer Product

Table 15 "Human Values Often Used in System Design" in other databases

Plant Database Value Comparative Analysis I - Based on values defined in (Friedman, Kahn, and Borning 2006, 17–18)

Human Value (of Ethical Import) Often Implicated in System Design	**Direct Quote Value Description –** (Friedman, Kahn, and Borning 2006, 17–18)	SAGE	CalFlora	USDA	UF/IFAS EDIS	TOLN	Natural Capital
Human Welfare	"Refers to people's physical, material, and psychological well-being"	x					
Ownership and Property	"Refers to a right to possess an object (or information), use it, manage it, derive income from it, and bequeath it"	x	x		x	x	x
Privacy	"Refers to a claim, an entitlement, or a right of an individual to determine what information about himself or herself can be communicated to others"	x					x
Freedom From Bias	"Refers to systematic unfairness perpetrated on individuals or groups, including pre-existing social bias, technical bias, and emergent social bias"	x					x
Universal Usability	"Refers to making all people successful users of information technology"	x	x	x	x	x	
Trust	"Refers to expectations that exist between people who can experience good will, extend good will toward others, feel vulnerable, and experience betrayal"	x	x				x
Autonomy	"Refers to people's ability to decide, plan, and act in ways that they believe will help them to achieve their goals"	x	x	x			x
Informed Consent	"Refers to garnering people's agreement, encompassing criteria of disclosure and comprehension (for "informed") and voluntariness, competence, and agreement (for "consent")"		x		x		
Accountability	"Refers to the properties that ensures that the actions of a person, people, or institution may be traced uniquely to the person, people, or institution"	x			x	x	x
Courtesy	"Refers to treating people with politeness and consideration"	x	x				
Identity	"Refers to people's understanding of who they are over time, embracing both continuity and discontinuity over time"						
Calmness	"Refers to a peaceful and composed psychological state"						
Environmental Sustainability	"Refers to sustaining ecosystems such that they meet the needs of the present without compromising future generations"	x	x		x	x	x

Table 16 Community Values in the other databases

Plant Database Value Comparative Analysis I - Based on values defined in Section 4.2

Community Values (defined in Section 4.2)	Value Description	SAGE	CalFlora	USDA	UF/IFAS EDIS	TOLN	Natural Capital
Earth Care	Refers to the permaculture value of rebuilding natural capital	x	x	x	x	x	x
People Care	Refers to the permaculture value of looking after self, kin, and community	x		x	x	x	
Fair Share	Refers to the permaculture value of setting limits to consumption	x					x
Quotidian Insubordination	Refers to a person's ability to engage in typically anonymous, every day forms of resistance, even if illegal, against consumerism and industrial agriculture.	x	x	x			x
Empowerment	Refers to a person's power to engage in, for example, growing food and reduce risk of environmental contamination and health complications.	x			x	x	x
Selective Use	Refers to a user's ability to decide the degree to which an IT should be utilized to achieve their goal in contrast to ITs that encourage high-usage driven by, for example, profits.	x	x	x	x	x	x
Modularity and Multiplicity	Refers to the ability to stack functions of resources – Use hardware and information systems for many purposes.	x	x	x			
Longevity	Refers to the extension of an IT life line to reduce the frequency of e-waste	x	x	x	x		
Food sovereignty	Refers to participants' belief that people should have long-term access to food and opportunity to grow food.	x			x		x
Regeneration	Refers to the long-term concepts of breakdown, evolution, and growing anew as applied to community, renewable and non-renewable natural resources, and infrastructure.	x	x	x	x	x	x
Sociocultural equality	Refers to long-term equal opportunity to participate in the formation and possession of sociocultural capital, knowledge, critical resources, infrastructure, and traditions.	x	x		x		