Permaculture as a Systemic Design practice: Contributions, challenges, and new developments

Cassel, John Benjamin

John Benjamin Cassel

Permaculture as a Systemic Design Practice

Contributions, Challenges, and New Developments

Abstract

The discourse on design has often situated it as a science of the artificial, but it has always been necessary to design our interaction with natural systems as well. One tradition for doing so is permaculture, a systemic design approach that aims to develop sustainable (permanent) agriculture and settlements. This paper will present permaculture's relationship to systemic design, providing historical context to understand its ecological, agricultural, and design origins. Permaculture has made many contributions to systemic design, including simple-to-remember lists of guiding ethics and principles, a clever vocabulary of categories that allow the discussion of interactions, a toolbox of design methods for selecting and assembling systems of elements, overall design processes, and some agroecological and social system design insights. However, this exchange of ideas can go both ways, as there are current challenges to permaculture in which systemic design can assist, including forming objectives, assessing appropriate technology, stakeholder engagement, and launching viable projects. From there, this paper highlights new developments that show progress in addressing these challenges, and illustrates that systemic designers can join permaculture practitioners in these efforts. Overall, agroecological design is an area of systemic design that shows much need and promise.

Introduction

The discourse on design has often situated it as a science of the artificial (Simon, 1996), an understandable side-effect of the new needs posed by industrialization and urbanization. However, it has always been necessary to design our interaction with natural systems as well. One tradition for doing so is permaculture, a systemic design approach that aims to develop sustainable (**perma**nent) agri**culture** and settlements.

It is the right time for systemic designers to pursue the continued development of agroecological design practices such as permaculture. Progressively we are seeing that the are opportunities for real systemic design in natural systems, design possibilities that break past the artificial dichotomy between the purely natural (public and set aside) and purely artificial (private and for total singular use) to more sophisticated balances that allow natural systems to be configured for a variety of roles and trade-offs (Oudolf and Kingsbury, 2013), leading to the field of ecological engineering (Mitsch, 2012). There can be no doubt that undertaking such a re-balancing would have impacts in the design of food production systems, utility provision, housing, and regional planning. Even in food production systems alone, this spells out the possibility for a science of agroecology (Lovell, 2012) and an agroecological engineering which applies it (Lescourret et al., 2015). If developed, an agriculture based up perennial-based polyculture could have excellent consequences (Dewar, 2007). With a science and engineering practices developing, we should also develop design practices that appropriately integrate these new findings into society.

This paper will first define permaculture and provide historical context. Next, it will present permaculture's relationship to systemic design. Then, we will explain some notable aspects of permaculture's design approach. From there, we will examine current challenges to which systemic design can assist and provide a methodological approach to one of them. After this, we will highlight new developments that show progress in addressing these challenges. Finally, we will look to future work that can address more of these challenges and conclude.

History and Context

A simple definition is that permaculture is a design system for ecologically responsible home economics understood broadly. From a scholarly perspective, permaculture is a notoriously multi-faceted approach, evolving aggressively from its agricultural origins to culture-wide applicability by allowing shifting definitions to suit particular needs, an evolution it shares with the design profession. Having said that, a systematic inquiry into permaculture literature (Ferguson and Lovell, 2014), describes permaculture in its totality. In this account, permaculture is an international and regional movement of bioregional networks and itinerant teachers that disseminate and practice both a design system, consisting of eco-design principles and spatial strategies emphasizing site specificity, synergies between components, and land use configuration in order to select and integrate practices for site- and user-specific goals; and a best practices framework which evaluates and adopts practices for ecosystem mimicry and system optimization emphasizing perennial polycultures, integrated water management, and alternative crops to produce an evolving bundle of favored practices, all contextualized by a worldview emphasizing the human role as ecosystem managers, encouraging volunteerism and individual action with the belief in the effectiveness and appropriateness of simple solutions.

Though permaculture's branches have flowered in many different directions, its origins and source influences are clear. Australian university lecturer Bill Mollison and undergraduate David Holmgren co-originated the concept during their academic collaboration from roughly 1976 to 1978, culminating in the publication of *Permaculture One: A Perennial Agricultural System for Human Settlements* (Mollison and Holmgren, 1978), later described as a transcription of notes of their effort. The interest in the first volume apparently took Mollison by surprise (Mollison, 1979), and he continued developing and teaching the material, leading to both the influential Permaculture Design Certificate educational program and to a massive designer's manual (Mollison, 1988). Much later, Holmgren returned to permaculture writing, producing his own foundational text (Holmgren, 2002) and other work, including some foresight regarding future trends (Holmgren, 2009).

Permaculture's source influences are a powerful combination. J. Russell Smith's *Tree Crops: A Permanent Agriculture* (Smith, 1929) proposed a similar permanent agriculture system, without the design elements, fifty years in advance. Permaculture's confidence in acting on a systemic ecological basis was directly influenced by the father of ecological engineering, Howard Odum (Odum, 1971). That permaculture is formulated as a design discipline can be partially credited to reading the first edition of Papanek (1984) and discussing the work with the author. Permaculture's strong emphasis on farm water management practices were adopted from both reading from (Yeomans, 1981) and discussions with the author, a mining engineer turned farmer and farming equipment innovator who discovered a topology-based water provisioning strategy. Masanobu Fukuoka's *One Straw Revolution* (Fukuoka, 1978) was a contemporary of Permaculture One and by Permaculture Two as already showing an influence in terms of agricultural approach, natural lifestyle, and dedication to observation, if not in terms of his philosophy of 'understanding nothing'.

Permaculture spread quickly, due in no small part to the Permaculture Design Certificate (PDC). Mollison found that he could deliver many of the key ideas in a short 72-hour course. The courses contained a viral element, such that those who went through the course were then eligible to teach the course using the same curriculum. This teaching program, when combined with international conferences called permaculture convergences, spread permaculture in a viral way. This alternative educational program, combined with Mollison's distaste for academia and occasional alignment of various practitioners, also led to permaculture not being pursued in conventional educational channels. As another side effect, particular lineages of teachers have different emphasis, and the genealogy to Mollison is one consideration in evaluating a PDC. Practitioners often take multiple PDCs with different genealogies to enrich their understanding.

Though, the agronomic material in the initial works and teachings had many elements specific to Australia, a number of books focused on North America and Europe have adapted the material to colder climates (Hemenway, 2009; Jacke and Toensmeier, 2005b,a; Falk, 2013) following on from the forest gardening work of Robert Hart and Martin Crawford in England. In addition to being similar in climate, tropical and subtropical areas also benefit from having perennial vegetables as part of existing cultivation. In these areas, the promotion of permaculture might be more a matter of protecting working indigenous systems as opposed to developing or rediscovering systems of local design, leading to a natural alliance with the agroecological study of these regions.

Today, the permaculture community takes full advantage of contemporary communications approaches with websites, online videos, and podcasts. A recent trend has been less of a focus on farms and gardens as such, but also on urban and suburban life (Hemenway, 2015), with particular interest in political and social action. Two notable design movements stemming from permaculture are *Transition Towns* (Hopkins, 2008) and *Food Not Lawns* (Flores, 2006). *Transition Towns* is a movement of civic organization aimed at creating municipally-accepted comprehensive plans for transitioning to localized and resilient low-energy operations by means of mobilization, dialogue, retraining, and organizational design. *Food Not Lawns* encourages the conversion of lawns to gardens and related community-building activities such as seed and harvest sharing. With viable movements and a substantial readership, permaculture maintains substantial public interest.

With this understanding of permaculture, let us now discuss permaculture's relation to systemic design.

Permaculture Practitioners are Systemic Designers

Before making the claim that permaculture practitioners are systemic designers, we need to make clear what systemic designers are. For our purposes, design is the redirection of attention through considered affordances and communications. While all humans are designers of some kind by virtue of planning or patterning our acts to meet desired ends (Papanek, 1984), there are design professions which study both processes to determine what others practically desire as particular ends and specific systems of patterning and planning to satisfy those ends. Systemic design is the recognition that the current configurations of patterns and plans often overwhelm or undermine the effect of any particular product or service and accordingly seeks more thorough transformations. Systemic designers are people who design mindful of this recognition.

There are several ways that permaculture is a contemporary design practice. First of all, permaculture arranges its training and professional activity in a way similar to design. In addition, permaculture practitioners undertake design processes, engaging in a period of goal discovery and analysis prior to action, encouraging prototypes, experimentation, and local adaptation. Also, permaculture undergoes challenges in its relation to science, showing some of the same tensions that emerge in design.

The first thing we should understand is that permaculture practitioners have the same professional paths as designers, where those interested in permaculture obtain one or more certificates in permaculture design consisting of a brief introduction to both theory and practice, and then engage in a series of apprenticeships and volunteer projects in developing sites, before finally engaging in design services.

Permaculture practitioners undertake design processes and have specific design methods used to develop questions discovered in those processes, where these design methods will be immediately familiar as spanning the variety of design research approaches, including observation, ethnography, functional design, analysis, dialogue and group facilitation, foresight scenarios, diagramming, random combinations, sketching, and so forth (Mollison, 1988; Flores, 2006; Hopkins, 2008; Falk, 2013; Holmgren, 2009).

Permaculture has both internal and external dialogues about how scientific it is supposed to be and its relation to the scientific community (Ferguson, 2014b; Ferguson and Lovell, 2014; Ferguson, 2014a), reminding one of the development in design from design science to design thinking (Cross, 2001). To my mind this difficulty is a sign that permaculture is a design practice, which per Nigel Cross is neither science or humanity but an application of the two into a third discipline which provides appropriate solutions to particular problems, whether through scientific application, development of participant subjectivities, or single-case problem solving (Cross, 1982).

Perhaps more than any other criteria, permaculture is a systemic design practice because it provides practices for people to design positive and meaningful roles in systems. Following Raymond Lowey's *Most Advanced Yet Acceptable* (Sterling, 2005) motto, there is a clear articulation of that which is most advanced: which is to both steward an ecosystem and provide for one's own needs, the needs of one's family, and contributing to the needs of the community, and consuming no more than necessary to maintain that state of affairs. Recognizing acceptability has perhaps been longer coming, but can readily be seen in the community and civic organization elements of recent permaculture works.

Having established that permaculture practitioners act as systemic designers, let us now turn to the contributions of permaculture design to systemic design.

Contributions of Permaculture Design

With so many years of development by de-facto systemic designers, permaculture has made a number of contributions to systemic design. These decades of contributions are too many to be surveyed appropriately, but many of the original works are still of strong current influence and can be treated as generally accepted. For that reason, we will consider permaculture's design contributions with a particular attention to materials from *Permaculture: A Designers' Manual* (Mollison, 1988), hereafter abbreviated as PADM.

Even the order of PADM is useful to this explanation and we will follow its order here. First we examine permaculture's simple yet powerful guiding ethics that both suggest and help evaluate potential designs. Next, we will look into a clever vocabulary of categories that create an combinatorial approach to assembling systems of elements. This paper will then look at how this combinatorial approach, along with other design methods and a knowledge of common design patterns, creates a progression from patterns to details that assures appropriate techniques are used when developing systems. Finally, some of the specific insights in designing agroecological and socioeconomic systems are highlighted.

Ethics

PADM immediately starts with developing its ethical philosophy, the very first line being 'Although this book is about design, it is also about values and ethics, and above all else about a sense of personal responsibility for earth care'. This is a powerful asset to permaculture teaching, immediately establishing that any particular methods or processes are only appropriately employed in the context of right means and outcome. The first page lays out the prime directive of permaculture: 'The only ethical decision is to take responsibility for our own existence and that of our children. Make it now.'

The commitment to ethics continues immediately with the next chapter subsection (1.2) being entitled 'Ethics', which proceeds to articulate 'The Ethical Basis of Permaculture', quoted as follows:

1. **Care of the Earth** Provision for all life systems to continue and multiply.
2. **Care of People** Provision for people to access those resources necessary to their existence.
3. **Setting Limits to Population and Consumption** By governing our own needs, we can set resources aside to further the above principles.

Of these, the third point has been proven not to be entirely adopted by the permaculture community, with *Gaia's Garden* (Hemenway, 2009) listing the ethics as 'caring for Earth, caring for people, and reinvesting the surplus that this care will create'. One occasionally hears the abbreviated 'Earth care, people care, and fair share', further developing the ambiguity between only taking one's fair share and sharing as to produce a communal use of resources. The first two points seem to be uncontroversial in the permaculture community.

How is it that permaculture might have specific, agreed-upon ethical precepts when other design fields, such as industrial design, graphic design, or interaction design do not? It may be that to think of permaculture as a similar design discipline is a category error, as some permaculture teachers prefer to the approach to be known a 'toolbox' rather than a specific set of tools for any particular technical subject. These ethics then form a criteria for when tools are appropriate to bring to a particular task. In this way, permaculture might be better thought of as a design paradigm instead of a design discipline, perhaps an agroecological extension of the design science tradition.

With this ethical basis providing a lens on what is to be considered a topic of permaculture design, we can now establish some principles that establish how it treats these topics systemically.

Design Principles and Vocabulary

To set some context, permaculture design, particularly in terms of vocabulary, is undergoing an exciting transition. Where permaculture terms used to be landscape-specific, the community is finding ways for them to be more generally applicable. As a result of this development, there are existing cartographic representations for the spatial layout of many of these elements, but there yet to be graphical conventions for adopting them in more general terms. I hope those versed in graphic design see this as an opportunity to develop new forms of visual communication and diagrammatic processes.

Permaculture design involves arranging design elements structurally and temporally into functional inter-relationships, looking to make sure that outputs become inputs, problems become solutions, necessary functions are provided for redundantly, and whenever possible elements have multiple functional uses. These interrelationships are developed with attention to beneficial, neutral, and detrimental interactions. These elements are subject to contextual factors that constrain their appropriate place within the design, if one is to be found. The overall objective of such arrangements is to produce yield, or surplus over self-sufficiency of the system itself. Yield is to be understood not only in terms of the amounts of products produced, but also as any energy produced by, captured, stored, conserved, or converted by the system.

Ongoing systemic yields are to be maintained through attention to the nature of resources used, preferring those that increase with modest use, those unaffected by use, and those that disappear or degrade if not used over those that are reduced by use, and preferring those over means which pollute or destroy other resources if used. Therefore, maintaining cycles is a key means of stewarding resources, with every link in a cycle constituting further yield. From PADM: "Cycles in nature are diversion routes away from entropic ends - life itself cycles nutrients - giving opportunities for yield, and thus opportunities for species to occupy time niches."

These elements often require different levels of attention, and we want to have elements that require similarly frequent levels of attention to be arranged together for efficient engagement. We can note where in the system it takes effort to attend to, so that we can arrange elements requiring frequent attention as to take low effort, and that requiring little attention requiring higher effort to attention. A clustering of elements into an equivalent level of effort to attend to is called a zone. Originally, these zones were explicit partitions of the landscape, by default proceeding out in concentric rings from a residence. Zones are traditionally numbered one through five, with the following implications: 1) elements to be placed near the immediate household as they require close observation, frequent visits, or daily work input; or producing daily yields 2) elements to be placed reasonably close as to be considered ready for domestic consumption, such as further built infrastructure, household services requiring less tending, and physical features which protect and provide for the house 3) commercial crops and field shelters, feed stores and silos 4) areas that are transitional to wilderness, often woodlands, for fuel, infrastructure, forage, and recreation 5) wilderness, which is not to be called upon except in emergencies, but to be explored for ideas. However, these zones can be adopted to other purposes than arranging a landscape. For example, when considering personal interactions in a phase in a project, we might say that a person we'd work with every day would be a one, while somebody who might only see the final presentation could be a four. As another example, an urban person unable to grow their own food might consider their neighbors with gardens a primary resource (say two), followed local farmer's markets (three), then a co-ops trading fairly (four), and ideally only have to visit conventional markets under rare circumstances (five).

Depending upon their location within the structure of relationships, different elements might be impacted differently by external factors, and we want to locate those elements as to react most favorably to those conditions. A particular set of similar external conditions is called a sector. These sectors are stereotypically arranged in pie-shaped wedges from the residence, and indicate changes in climate due to seasonal sun angles, exposure to wind, and other similar differences. It is becoming increasingly recognized that sectors can change over time, at different characteristic rates, and that we have to be prepared for the different scenarios those changes might bring. Even in the natural realm, sectors might include exposure to neighbor sight-lines, proximity to the road and thus exposure to exhaust, and other differences in exposure. The concept of sectors can also be expanded to categorize any difference in external impacts. In a project, we might consider who we wish to speak to the press in order to be most effective. Sectors can include regulatory aspects: which properties are subject to certain laws. Overall, the consideration of external relationships and impacts is key to selecting which elements can be part of a system, and where in the system they most appropriately function.

PADM explains zones and sectors with respect to permaculture's orientation to managing energy resources and cycles in a broad sense: the zones establish the flow of energies in the system, while sectors establish the flow of energies through the system.

A known set of elements working together functionally, with connected output-to-input relationships and no undermining detrimental interactions, suitable to particular conditions, is called a 'guild' in the permaculture literature. However, 'guild' is a particularly unfortunate choice as that term means exact opposite in ecology, referring to a group of organisms that share the same niche and would compete with each other. The word team implies the underlying concept much better. The characteristic of good teams is that the elements serve each other functionally and belong in different niches. One important category of niches for agroecological purposes is layers which explain how different plants can accommodate each other spatially: rooting plants, ground covers, mushrooms and other fungi, small plants such as herbs and vegetables, shrubs, small trees, large trees, vines, and water plants. The idea of niche can also be adapted outside of ecology, such as workers who may take different shifts.

With these principles and vocabulary understood, we can now contextualize what the design activities of permaculture contribute. Let's turn to those now.

Permaculture Design Methods

Permaculture allows any number of design methods, with PADM stressing the value of indigenous and scientific knowledge-bases to appropriate use, giving credence to nearly any path to practical knowledge. As an illustration of this methodological permissiveness, here is one listing from PADM of potential means by which solutions might be found: improving tools, collecting a large set of observations, insight (Eureka moments), trials, guessing, responding with close attention to unique or strange events, being open to accident, imitation, patterning, and constant adjustment to feedback. As mentioned above, permaculture uses any number of design research techniques familiar to all, including observation, flow diagrams, biomimicry, decision planning using both forward and backward steps, and making maps with overlays. However, there is body of approaches that characteristically defines the analytical side of permaculture methods, namely the combinatorial making of teams arranged in a system as to accommodate zones and sectors. The rest of this subsection will be devoted to explaining this cluster of methods.

First, we can presume to have an initial set of required elements, such as the people intending to live on a property, as well as an initial set of candidate elements. By default, this system is the household of the individual designer and the candidate elements are various ecological, built, and social structures needed to support them. We then consider viable settings in which to situate this system. For each potentially viable setting, we determine sectors. This first step of the problem is to situate the problem.

Next, we move on to the selection step of the problem. For each unaddressed need, we select some of the candidate elements or teams that can undertaking processing, production, or maintenance that meets those needs. In particular, detect wastes and avoidable work, introducing new elements to process those wastes and substitute for labor. We then filter out those systems that fail to meet the considerations imposed by any sector. We then look to the needs imposed by the new system that contains these elements. In this selection phase, we often want to start with the functions typically used to solve those needs and the needs of the members of the system. For example, in a garden, we'll likely want species that attract pollinators as that is a common needs. When a permaculture design can speak entirely in terms of networks of functionality and need, and then later determine the elements to meet those needs by considering the sectors, layers, and zones, we've encountered a working example of the permaculture design dictate to work 'from pattern to detail'. This is effectively the engineering design approach of determining sequences of functions and flows, then inferring designs with function/component matrices (Bryant et al., 2005; Hirtz et al., 2002).

If at any time we have a system that requires sufficiently minimal inputs and produces sufficiently minimal wastes, we are provisionally done with the selection step of the analysis. We may reasonably be content just to improve the current efficiency of the household. This design process can be undertaken iteratively and it is good to extend a basic viable system outward rather than be overwhelmed by trying to manage a complicated system with unforeseen complications.

Once we have a what may be a viable set of elements, we estimate its interaction requirements and assign a zone. If we have too many elements for a given zone, that will disqualify this path of candidates. A set of elements may not be viable for other reasons, such as initial cost, and should also be filtered by these other standards.

If a candidate system has too many unmet needs, but still seems viable so far, we continue iteratively by finding systems that meet these unsatisfied needs. We find some number of other sets of elements that satisfies the needs of the initial set. We try each of these in turn by order of apparent promise, observing the new set of needs added by these elements. Overall, selection produces a search tree of candidates, stemming from our initial needs, to sites, then to satisfying elements, and then multiple layers of supplemental balancing elements, terminating each branch if the number of elements is not viable. However, the view of a search tree presents too static a view, and any potential need can cause research for new elements, and any particular element can cause research for potential needs and compatible teams.

Given we now have a set of potentially viable elements, we now want to see if they are logistically feasible. We now start the assembly step, which itself has a preparation phase followed by a combinatorial phase. First, we'd like to be sure that we have a good number of viable arrangements in case some are superior to another. To assure this, we first try some random assemblies. In order to do this, we list out all of the elements which we are aware, and also add connective words such as 'interacts with', or in problem-specific connectives, such as those concerning spatial layout: 'attached to', 'beside', 'around', 'under', 'containing', etc.

With this assurance that we've discovered more potentially appropriate routes for assembly, we can now establish a layout. In order to do this, develop heuristics for how to situate elements by looking at particularly good and poor arrangements on an individual-by-individual basis (Flores, 2006). Some placements will be nearly dictated a matter of common sense; attend to these first. Similar to many other matrix-based engineering design activities (Eppinger and Browning, 2012), a matrix between elements can establish how everything impacts everything else and determine necessary separations, as well as to establish the feasibility of a particular arrangement. Try situating elements and see that constraints are satisfied; any search approach is viable here. If this is being done without the aide of computation, try shuffling the items after each attempt to get a fresh view, jumping to potential overall arrangements if a pattern is perceived. If the project concerns a spatial arrangement of elements, create an overlay on top of the base map that shows their proposed layout, seeing that the spatial requirements of the elements are met. If undertaking a spatial arrangement manually, having a cut-out for each element and moving it into different positions, as though fitting a puzzle, can be suggestive. When situating elements in a design, be sure to consider the arrangements over time. With an overall arrangement, one is finished with this aspect of design and is ready to proceed to trying it out and adapting, with further design as appropriate.

Interestingly, although an analysis technique, this combinatorial approach does not specify in totality the kinds of elements that will be added or the sorts of problems which will need to be tackled. It is expected that in the course of adding elements to address problems that new facets will be discovered. For this reason, this method of permaculture design is one of those rare analytical techniques prepared to reckon with the unbounded character of real problems (Cassel, 2014).

Overall, this description should not be taken to mean that permaculture design is dominated by analysis, but this analytical process is a design procedure that is both relatively different than what other systemic designers do and also easy to describe. The approach to observation is also somewhat atypical, but in a way harder to describe. Let us now turn to the overall design process to get a better feel of where these techniques may come into play.

Permaculture Design Processes

Interestingly, PADM only provides a very skeletal design process for permaculture, actually explicitly listing out steps for a design process in a single diagram in the first chapter, and otherwise only providing principles, design methods, general patterns, ecosystem considerations, and potential mechanisms. This is fairly wise, as with so much to consider, some attempts to provide a comprehensive design process (Jacke and Toensmeier, 2005a) have been fairly convoluted and involved even when constrained to a smaller subject matter. PADM's process is to select species, people, materials and fuels, and financial and legal structures. It then looks to assemble teams, communities, technologies, constructs, trusts, companies, cooperatives, and community credit unions, while considering site-specific considerations in earth- shaping, water supply, and planting patterns. These assemblies are then patterned for best flow, function, and yield while conserving resources as a means of controlling the flow of these elements, while attending to the feedback of yields and function accomplished through observation, evaluation, and control mechanisms, overall constituting a total design through evolution to maturity.

As a different example, Food Not Lawns (Flores, 2006) proposes a complementary systemic process compatible with many permaculture activities.

1. **Undertake deep observation** Every permaculture process I've ever seen recommends starting with observation of every relevant facet, including both the resources to be stewarded, the present situation, and how various stakeholders, including the designer, currently live and feel about their situation. This observation should try to consider multiple spatial and temporal scales and engage many different modes of thought.
2. **Determine initial underlying goals and needs (with priorities)** At the point of deciding that something will be done, it is good to begin by stating what the desired end-result will be. As with all design, these goals can be the subject of iteration given experience, but it's good to have one pass at stating what is wanted without reference to any particular solution and develop an understanding of what does and does not constitute reasonable compromises or correct functioning.
3. **Undertake directed observation** With some goals at hand, we can start to observe the subject of those goals. Ideally, this observation takes place over the characteristic length of the subject, such as a growing season. At this point, it is useful to start forming potential ideas for designs and developing potential goals around the completion of particular solutions. Sketch potential ideas.
4. **Determine boundaries** Understanding the boundaries of a project means attention to physical, legal, political, social, and personal boundaries. If the work involves a spatial extent, build a base map. Understand existing regulation. Consider how the work will be undertaken, including when it will take place, with whom, for how long, with what provisions for rest, under which conditions the project will be stopped, and which of one's personal resources are available for investment versus what limits. Research neighbors or other stakeholders who may have conflicting interests and think through how to handle potential resistance.
5. **Inventory available resources** Designate the zones and sectors imposed by the situation. List out all elements directly available and examine their relevant conditions. If undertaking a project with spatial extent, produce an overlay of existing elements. If materials are to be purchased, list candidates with their costs and comparative attributes.

6. **Undertake analysis for placement and strategy** This analysis was described above in detail in the design methods subsection.

Given these general approaches, let us now look into some of the system-specific ideas common in permaculture.

Agroecological Design

The vast majority of PADM is given over to ecological design, first considering the generalizable interactions of ecological elements and then addressing particular environments holistically, ending with a chapter on aquaculture. Here, we will only talk about the general observations and not engage the material on specific environments, which may be better represented by texts appropriate to the reader's region.

Before proceeding to specific ecological considerations, PADM undertakes a transitional chapter on the study of naturally-occurring patterns such as fractals, spirals, branching factors, flow patterns, typical demographies of species populations, and the role of geometry in undertaking particular functions. These patterns are generalized ecological observations. One such observation is the productivity of the edge between two systems, such as between land and water, and how we can increase productivity by, for example, not having circular ponds but edges that zig-zag or have a fractal character increases their edge. Similarly, we can by the means of creating branching "keyhole" paths maximize the amount of access to a gardener per amount of access path. Edge is an attribute to be controlled but not necessarily maximized, as fragments of ecosystems can have a radically different character than those maintained cohesively (Jacke and Toensmeier, 2005b). PADM notes that these patterns are not constrained just to phenomena outside of human beings. In particular, practices that encode knowledge in stories, dance, designs, and other easily preserved cultural artifacts can retain as much appropriate advice as being aware of a natural pattern, and that there is a close relationship between natural and cultural patterns in some societies.

From there, PADM moves to a set of sections on fundamental ecological factors, dedicating chapters to climatic factors, trees (in particular how they affect climate and water cycles), water, soils, and earthworks. Through the growth of perennials including nut and fruit trees, we are able not to disturb the soil, building a food web that moves from predominantly bacterial to predominantly fungal soil, rich in organic structure, as well as avoid the efforts of replanting. This soil structure then holds water, and is protected by trees, which also contribute transpiration and altering wind patterns as to readily produce rain and thus develop a cycle of water. The topology of the land may lend itself to drought, flood, or erosion events that make it difficult to establish systems, and so a few smaller earth structures can lead to much better handling of the flow of water through the property. These include the swale and berm, where the swale is a trench dug upon contour to slow and spread the downhill flow of water, and a berm is a raised area immediately following it. This berm then suitable for plants that will then have a ready source of groundwater. Overall, with such systems, we will still need to attend to the extremes of a given climate, as well as how much sunlight is available (in foggy areas) to establish overall constraints on the given sectors, but with an attention to topology and the establishment of trees, a number of microclimates can be established to produce a variety of sectors. Together with the analysis, these factors determine nutrient flow, water cycling, and microclimate formation suitable to particular agricultural needs.

To those outside permaculture, the addition of earthworks must stand out as being not like the others. Here we can see permaculture's Australian influence, working in a land that needed to capture water and influenced by comparatively close access to the very long lasting terraced farming of Asia. The trick then becomes how to use structures like swales to keep water high in the landscape, and thus hydrate a broader area of land. This corresponds with the Keyline strategy of P. A. Yeomans. To understand the basic idea of this strategy, consider now two hills. Traveling down the steepest gradient from saddle point between them, there will be a point where the hill switches from concave to convex. This is the key point, the spot where water capture becomes quite feasible. Connect the keypoints of many hills with a swale as close to level elevation as possible and you have a keyline, and thus the basic unit of a water management strategy that can be elaborated much further. Here, we see one of permaculture's few recommendations for using limited resources such as fossil fuels, namely building up structures that will generate cyclic yields for thousands of years.

However, even the keyline strategy is contains a broader systemic concept, namely the scale of permenence (Yeomans, 1958), which is roughly similar to Stewart Brand's shearing layers idea (Brand, 1995) except having the virtue of predating it. The idea was to notice how the relative permanence of some factors determined the importance in which of the factors should take precedence over the others in the design, so that placing drainage tunnels for the advantage of a roadway might lead to the roadway being washed away. The scale of permanence he posed for the farm was, from longest to shortest: climate, landscape, water supply, roads/access, trees, structures, subdivision fences, and soil (he believed soil could be destroyed and built surprisingly quickly given the other factors and management practices). This scale of permanence has also been adopted into tools for social permaculture, which is the next topic we will consider.

Socioeconomic Design

With permaculture's ethical considerations, socioeconomic concerns were also on its agenda its initial founding. The final chapter of PADM, "Strategies for an Alternative Nation," is dedicated with these issues and is dedicated to describes desired new organizations and information resources in detail. To summarize, this description begins with a description of an alternative united nations of bioregional organizations, which themselves consist of both traditional and selected extended family arrangements. These bioregions are supported through trusts and similar legal strategies. Bioregional groups support the development of villages forming to offer services, such as community energy initiatives, employment offices, and recycling collection. The bioregions should group their resources to make profitable investments but go through filters to avoid sponsoring activities not in line with the ethics. These organizations should pay attention to future trends, such as deforestation due to deforestation, rising sea levels due to climate change, and the patenting of seeds and other natural resources, and take mitigating action. Aide reform is another consideration addressed, with an emphasis on locally appropriate solutions and a lack of dependency on development as an aide consideration.

As seen, PADM offers a great number of potential structures, but says relatively little on the process of how to transition into these structures, or even permaculture more generally. The Transition Handbook (Hopkins, 2008) does offer guidance in this area. This advice includes a long development period of raising awareness and interest before announcing formal initiatives, creating transition plans for leadership so that those who have served strongly in one stage can simply participate in other stages (which also avoids coupling transition to particular strong personalities but has a more robust community backing), advice for working with local and regional government, and context deploying various collaborative design methods, such as the World Cafe method. It also offers a great deal of framing useful to making personal transitions.

These works are by far from the final word on permaculture's social science methodology. One example is that the scale of permanence has been adapted into a broader tool, one that looks at the malleability of phenomena on one hand (as opposed to changeable, as a phenomena may change uncontrollably) to the permanence of the effect on the other. One such application is categorizing different stakeholder groups around a particular issue. One such analysis applied to permaculture education finds that permaculture may be easier to introduce at the secondary school level than in higher education (Bertrando, 2015).

Given this introduction to permaculture's contribution, let us now consider the systemic challenges it faces.

Systemic Challenges to Permaculture

Though permaculture's strong curricular footing is quite potent, no human endeavor is perfect and permaculture has many challenges (Ferguson, 2014b; Scott, 2010; Mann, 2015). Some areas where a systems designers can help includes technology assessment, stakeholder engagement, clarifying conflicting requirements, deployment logistics, project modeling, and information technology. This paper will take a deep look at shifting and conflicting requirements, establishing a taxonomy of objectives that fits with permaculture's systemic approach.

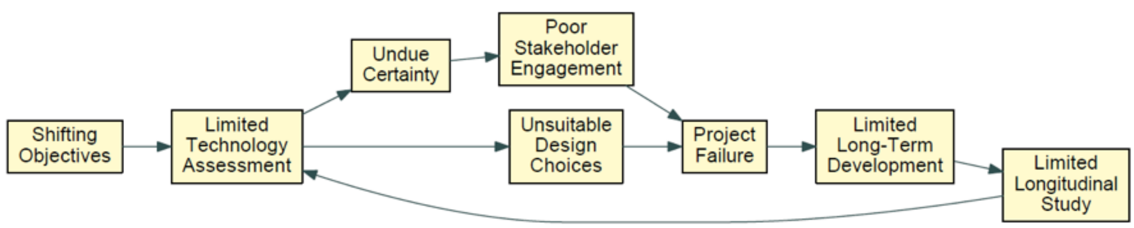

Figure 1. Permaculture's Systemic Challenges

Let us take a moment to summarize what these issues are and how they are systemically related to each other (see Figure 1). The broad number of potential objectives for permaculture designs often lead to shifting exactly which beneficial effects of those design approaches are being pursued, leading to problems of technology assessment in permaculture approaches. This shifting in what one is up to, but an ethical certainty in its appropriateness, can lead to unfortunate outcomes in engaging other stakeholders. Sometimes this poor social engagement and mistaken use of technique, along with questionable economic and social viability, leads to the downfall of particular projects. Overall, this contingency of success in particular projects erodes the capability to harvest permaculture's yields and set down regional roots. However, regional institutions are necessary for production and distribution chains to establish and take on longer-term ecological goals such as developing regionally appropriate varieties. The ability to take on these longer-term ecological goals is further undermined by the aforementioned lack of technology assessment.

There are many elements of the permaculture movement that many may find problematic, but which systemically cut both ways. Permaculture is open to extra-scientific experience and knowledge (PADM: 'The pragmatic and practical approach to the main body of this work largely omits reference to those visions or beliefs classifiable as spiritual or mystical; not because these are not a normal part of human experience, but because they are arrived at as a result of long contemplation or intense involvement with the mysteries that eternally surround us.') and directly political radical. This unquestionably neither recommends nor condemns ritualistic mystical practices, such as biodynamics, or extreme political philosophies, such as anarcho-primitivism, that are common in some permaculture circles. Their only harm emerges in supporting undue confidence in approaches or by creating problems in stakeholder engagement, while offering the positive aspects of offering further channels for the core ideas to take hold and offering additional lines of strident support. Those interested in practical outcomes maintain a big tent.

Among the systemic needs permaculture uncontroversially has, shifting objectives seem to be a root issue. Let us now try to make dent in that problem.

Avoiding Shifting Objectives

What we will see is that the definitions of permaculture can focus or constrain the way objectives are formulated, allowing them to be clearly differentiated. Indeed, the ethics, principles, and corresponding forms of analysis lead to objectives having a particular form. Let's start by defining objectives and figuring out what kinds of objectives we might support.

An objective is the observation/commitment that conditions are better by some criteria should some facet be made present, absent, greater, lesser, or closer to a particular. These criteria designate a particular scope, such that two objectives with different criteria might not have any clear way of determining an appropriate trade-off between them. There are two different kinds of objectives, which we will call constraints and goals. We are obliged to meet constraints, or we cannot go forward. A particular design fails an economic constraint if we cannot summon the labor, capital, or resources to do it. If someone says “Organic farming is not economically feasible”, then they must be referring to a constraint on all food being grown organically, because clearly some farmers are following organic farming practices. For a goal, the closer we get to some target amount, the better things are. Someone could instead say “Organic farming is not economically competitive”, which would mean that although one can actually farm organically within existing economic constraints, other means will be selected due to being more profitable, which is more difficult to evaluate. In short, one can pursue different goals at the expense of others, but one cannot pursue different constraints. We say a constraint is active in a particular system if it is limiting any improvement in goal performance.

Given this understanding of objectives, let us start by saying what we mean by shifting objectives. Objectives shift when they are added and removed in an ad-hoc way during a design’s evaluation, leading to some approach seeming like it is better while it actually meets the desired intentions poorly. In addition to rejecting some alternatives due to an ad-hoc subset of the overall criteria, we can try to make cases based on objectives that are actually poor stand-ins for other criteria. For example, in terms of agricultural yield, pounds per acre per energy input versus calories per acre per dollar are proxies for the needed nutritional contribution of the yield undertaken in an way that is most efficient while continually feasible. What we would like to do is design an organization for objectives compatible with permaculture’s approach.

As the ethics are very expansive, where can we begin? To start, let us partition objectives by their scope into why, what, and how. Said differently, we are after grand strategic, strategic, and tactical objectives (Tow, 2003). Some permaculture designers refer to these as values, goals, and criteria (Jacke and Toensmeier, 2005a), but these terms are defined differently here. This will let us temporarily defer relevant tactical objectives such as “20 bushels of apples per year” until we have the information architecture to maintain them and assess their appropriateness.

Given this, we are after statement of grand strategy that establishes why we adopt some objectives and not others. Overall, we want a grand strategy that embraces conceptual work already done by permaculture: the assembly of elements into arrangements that meet their own needs and provide additional yields continually by means of arranging cycles for processing all wastes and producing all work.

Therefore, a viable grand strategy for permaculture is to maximize the sustained flourishing of the resource-renewing cycles in which we participate. This strategy articulates both a care for the environment that sustains our life and the necessity of a human role in that care. It does not neglect education or traditions but recognizes that human development is vital to our ongoing participation. Yet, it does leave out a variety of contemporary activities that we might care for ourselves better without. From this strategy of sustaining resource renewing cycles, we can identify three other key strategic goals: directly fostering renewing cycles, minimizing activities that disrupt those cycles, and minimizing dependencies outside of those cycles. Even at this degree of abstraction, we have a useful conflict between applying external resources to the first two for short-term growth, and not utilizing external resources to satisfy the third, for long-term stability.

How do we approach these cycles strategically? To maintain our households and take responsibility for our lives, we should start with the cycles we have no choice but to be a part of, including oxygen/carbon dioxide, water and food/effluent, clothing and shelter/spent fuel and worn fibers. Thankfully, oxygen requires effort under rare situations. Necessarily, we are also paying particular attention to the interaction afforded to us by our locality and its surroundings, perhaps moving or altering our location to allow more interactivity or choice our cycle participation.

Given that a core need is establishing cyclic biological cycles for food and energy, let us look at some of the strategic objectives that growers, broadly understood, might have. Growers could be interested in having enough good food at any particular time, developing plant and soil life to assure that stays so, establish water resource security, capture carbon, engage in healthy activity, being outdoors, being productively and personally engaged with both human and non-human others, engaging in exchange (including economic exchange), producing fiber, producing shelter materials, producing medicines, and acquiring and maintaining tools.

The idea that we're talking about our role in cycles allows us to categorize goals analytically. When attempting to design a section of any particular cycle, we can see that we're either talking about producing an input, processing an output, maintaining the character of a linkage, or some combination of these. We should see that this analytical breakdown of objectives is the same as permaculture's analysis of systems, which looks to introduce elements that process undue surpluses or produce resources that are deficient, while still maintaining needed yields.

First, let us look at some ways to consider gross yield, or total outputs. The simplest thing to do is just to put what one harvests on a scale and measure the pounds of yield, but clearly this is a crude proxy for any real end goal. It would be slightly better to measure pounds of consumable food, but what we're really after is human use of the yield. A different place to begin is the calories produced, and perhaps only the human-consumable calories, though fuel yields may also be desirable. Recognizing that we do not live on calories alone, more nuanced choice looks to a balanced full-spectrum human nutrition and hydration. This means that liters of potable water captured might be an important objective in its own right. Of course, over the scale of a lifetime we often need something more than our daily meals, so medicine per related human medical incident is also an important objective.

Some sectors have a greater capability for particular yields compared to others, and even within sectors particular teams lead to particular advantages along some nutrients compared to others, and both of these factors lead to advantages in trade and exchange. Given this, we are interested in full-spectrum cross-resource yields on average across systems: a given acre producing a wide spectrum of yields might not be the best solution. We can look at the current market value of the yield as one proxy, while looking at historical prices might give another, one with different trade-offs given technological limits that might reflect future constraints. Overall, it is a useful restriction to not see profit as an objective in itself but as a mechanism of accomplishing other objectives. In any case, we have to presume the value or cost in dollars of any particular yield or input will change as conditions change across the horizon which the objective is evaluated.

Another gross yield is the capacity to process inputs that otherwise would be wastes. At the boundary between agricultural yields and other systems we might want to remediate various pollution issues. In a different direction, one powerful input is to store carbon as organic matter in the soil, plant, and fungal matter instead of in the atmosphere.

One final kind of gross yield measures how well a diversity of particular cycles are maintained. This can be measured by the populations of particular species, acres of particular ecosystems, or people engaged in particular regional lifeways. These numbers have both intrinsic merit, but may also serve as relatively short term proxies of longer-term performance in other objectives. Given the complexity of ecology, it may be better to measure how constant these indicators remain, say the number of species in an ecosystem per area, to see if the ecosystem is actually preserved given its new dimensions. Along with ecosystems, this is where the state of the grower is taken into consideration, measuring how active they are in the systems they prefer.

We've now considered some gross yields, but now let us consider the modifications to net, by looking at the denominator. Each of the above is clearly per unit of comparable land (per acre) and over a given period of time (per year). We also want to discount inputs, as a way to minimize interfering processes and dependencies, so we can discount each calorie of fuel energy spent in production, processing, and distribution, or again normalize per current or historical dollar of input. Often, the active constraint is human labor available, so per person engaged is an important criteria.

When considering any particular mix of net yields, we will need to qualify the period under evaluation. For any particular group of people, a food system must deliver food very frequently so that people can eat as often as they need, multiple times a day. Once this constraint is met, we can then look at net performance over a variety of time-scales. To allow the easy comparison of different cycles of production, we might want to look at a yearly yield. However, to allow for the convenience of the year, but to take longer-term effects into comparison, we might want to amortize across years for yields and costs. Some such longer time-scales include: by decade, across a grower's career, across a grower's lifetime, across the lifespans of all currently living people, across the lifespan of any living organism in a system under consideration, across seven generations, across all impacts of our actions, and across perpetuity. By necessity, the longer the period measured, the more the consequences of internal actions become manifest, such that sustainability, but also the greater potential variability of external conditions. It seems that the right horizon is to carry the standard of continual present viability as far forward as can be projected, in order to get to systems that are currently feasible, likely robust over further conditions, and acceptably meeting goals throughout.

As we examine a given set of objectives, what we will want to do is not attempt to project their performance according to set of definitive conditions, but look to all plausible scenarios, or sets of conditions, when evaluating which designs that are robust across them. This subject of technology assessment in permaculture deserves its own treatment and will be left for future work.

Before leaving this topic, it is worth offering some methodological advice to capture objective shifts. The idea is that instead of shifting objectives, what we really want to do is add them, so that we now have a Pareto space in which meeting some at the cost of others is now a possibility. We would also like to move secondary objectives (i.e. "you can't meet this objective reliably without meeting these other objectives") out of designing the objective space, and into technology assessment. This leaves us with further future work, which is designing information technologies, suitable to both manual and computerized, that allow this objective space to be preserved and assessed against appropriate assessment horizons on a weighted basis.

With this small suggestion for systemic improvement, let us now look briefly at new developments in the permaculture community.

Recent Developments in Permaculture

The permaculture community is quite aware of the challenges that it faces and is taking a variety of positive actions. It is building viable projects that will last, based to one side broad surveys and demonstrations, but also on focused longitudinal work.

First of all, in order to have permaculture projects last, both for their own sake and to get the longitudinal data necessary to truly learn best practices, we need projects that succeed. Inside the permaculture community, there has been the recognition that pragmatic, profitable, broadacre-scale approaches are necessary for working farmland to be allocated to permaculture applications. For this reason, Mark Shepard and others have been developing the restoration agriculture (Shepard, 2013) approach, which is a silviopastoral system mimicking savanna ecologies.

This approach still makes radical steps forward, such as not using any pest controls other than population ecology, but does make some important and appropriate concessions. First of all, the cropping system does not focus on developing new perennial crops but focuses on crops and products with existing mass markets (chestnuts, hazelnuts, apples, cherries, plums, peaches, raspberries, blueberries, gooseberries, currants, cattle, pigs, chickens, mushrooms, and honey). The second is to allow operations with widely available equipment, such as nut harvesters (often powered by on-farm biofuels).

Preliminary analysis indicates this system provides superior per-acre full-spectrum nutrition production and conventionally competitive mid-horizon commercial profitability through sharply reduced input costs (also a source of performance by ecological measures). This system does incur establishment costs but cushions them somewhat by retaining the ability to raise annual crops through alley cropping (the practice of planting the perennials in rows on contour with sufficient distance between them as to allow mechanized annual cropping operations). This system provides a clear technical approach amenable to scientific comparison now underway (Wolz et al., 2015)

Permaculture's scholarship has also seen great improvements. One notable set of contributions is the work of Eric Toensmeier, who has contributed great catalogues of perennial vegetables (Toensmeier, 2007), staple perennial plants (Ferguson and Toensmeier, 2014), and plant species appropriate for forest gardening (Jacke and Toensmeier, 2005a), and along with Jonathan Bates cultivated a great urban permaculture garden (Toensmeier and Bates, 2013). This scholarship has included gathering community knowledge about the site-specific appropriateness of perennial crops through the Apios Institute wiki (Apios Institute, 2015). This work attempts to develop the true breadth of perennial food resources.

In addition to the breadth of perennial food sources, the permaculture community could really use the depth of species-specific work, as many of the plants discussed have not seen any real development of varieties for climate tolerance, disease resistance, nutritional improvement, amount of yield, or any other desirable characteristic. One group working in this area around nut trees has been the Badgerset research corporation, who have worked steadily to improve varies of hazelnut (Rutter et al., 2015) and chestnut.

Overall, the permaculture community is pursuing the development of using viable methods with appropriately vetted knowledge. There are many other areas of recent improvement that are not covered here, such as a renewed attention to financial permaculture. It is appropriate to think of the role of systemic designers not as bringing new innovations to the community, but joining the work of improvement in a movement with an increasingly healthy self-critical and reflective side. With that in mind, let us now look to some areas for further development from the perspective of this work.

Further Work

Clearly, so much promising work lies ahead. Of course, the systemic challenges laid out above may each be tackled. The problem of stakeholder engagement is one area which clearly overlaps contemporary work on design methods. The clearest extension of this work will be to take on the question of technology evaluation. We will want to evaluate solutions not only against sectors as they stand today, but to fully embrace the futures-aware aspect of permaculture and engineer solutions resilient to what sectors may come to emerge. Experimental design must be handled thoughtfully as not to unduly delay progress: in a domain with a combinatorial explosion of possibilities, variable-by-variable control seems a dubious way forward. Altogether, the analytical side of permaculture has so many parallels to contemporary engineering design that it may just be a matter of extending and formalizing what is already there to establish a technology evaluation for its practitioners.

In each of these challenges, there may be some supporting information technology. In PADM, there is repeated reference to the power of information and the potential role of computing, but such developments seem little explored, with the exception of computing-supported communication. All of the information support systems that PADM describes could be laid out in relational terms and shared effectively using today's networking technology. The systemic development of information systems for permaculture is thus a major direction for development.

Combining the ideas of information systems and technology assessment is the development of systems that be sure critical angles are explored. One way to improve the economic and social viability of a project is to subject it to a comprehensive ontology that makes sure it has worked through all of the interconnections that justify its viability and value. There are now such ontologies for strongly-sustainable business models that have commitments to representing and designing for ecological, social, and economic outcomes (Jones and Upward, 2014; Upward and Jones, 2015). Surely these can be applied to aide permaculture projects from a systemic perspective.

Even beyond further new contributions, there is so much more that could be done in making introductions. There deserves to be a proper history of permaculture's further interactions with the design community after the initial period. There also should be papers focusing on comparative surveys of permaculture and systemic design approaches to ecological design and social systems design.

Conclusion

Overall, this paper is aimed to introduce permaculture as a set of systemic design practices that both offer much to and greatly benefit from interaction with the systemic design community. Permaculture offers systemic design a well-established path into the agroecological design necessary to complement developments in agroecological engineering. We have seen how permaculture emerged from a synthesis of ecology, agriculture, design, and planning to being a vital fusion with popular interest. We saw the many ways in which permaculture practitioner have similar training, methods, professional issues, and sense of appropriateness as designers. Permaculture has offered many design contributions, including a clear ethical mandate, a powerful set of design concepts, design methods including an open system-assembly process, design processes, and specific agroecological and social system design approaches. Permaculture faces a variety of systemic challenges, including clarifying objectives, assessing approaches, engaging stakeholders, building institutions, creating logistical networks, developing viable businesses, and developing long-term knowledge. It is clear that there are approaches to each compatible with permaculture's overall logic, as we saw with building systems of objectives that process, produce, or maintain with given costs as amortized over periods of time. Those in the permaculture community are making great strides in a number of areas of challenge, and it is our future work to join them in systemic improvement.

The work of agroecological systemic design is more important than ever. With herbicide-resistant plants progressively emerging, we may find that within fifteen years conventional agriculture approaches will not be feasible at the per-individual scale as it was in the past. Currently, many farmers are locked in and must continue working at this scale to amortize the cost of the equipment necessary to work at this scale. At the same time, the average age of farmers in the United States is now in the fifties. At the time in which change must happen, a transition to a new generation of farmers without the current debt structure may allow it to happen. The question is what a new generation of farmers will do with this new possibility. Will the legacy from this time of transition be a systemic triumph for agroecological design, or will we wait another generation with whatever consequences that entails?

References

Apios Institute (2015). *Apios Institute Edible Forest Garden Wiki.* http://apiosinstitute.org/, as retrieved Nov. 27, 2015.

Bertrando, N. (published February 11, 2013, as retrieved on November 26, 2015). *Permaculture Education and Research in USA: Expanding Connectivity between Island of Fertility.* Permaculture Research Institute, http://permaculturenews.org/2013/02/11/permaculture-education-and-research-in-usa-expanding-connectivity-between-islands-of-fertility/.

Brand, S. (1995). *How Buildings Learn: What Happens After They're Built*. Penguin Books.

Bryant, C. R., Stone, R. B., McAdams, D. A., Kutoglu, T., and Campbell, M. I. (2005). Concept generation from the functional basis of design. In *Proceedings of the International Conference on Engineering Design*, Melbourne, Australia.

Cassel, J. B. (2014). The methodological unboundedness of limited discovery processes. *FORMakademisk*, 7.

Cross, N. (1982). Designerly ways of knowing. *Design Studies*, 3:221–227.

Cross, N. (2001). Designerly ways of knowing: Design discipline versus design science. *Design Issues,* 17:49–55.

Dewar, J. A. (2007). *Perennial Polyculture Farming: Seeds of Another Agriculture Revolution?* RAND Corporation, http://www.rand.org/pubs/occasional papers/OP179, as retrieved Nov. 27, 2015.

Eppinger, S. D. and Browning, T. R. (2012). *Design Structure Matrix Methods and Applications*. MIT Press, Cambridge, MA.

Falk, B. (2013). *The Resilient Farm and Homestead: An Innovative Permaculture and Whole Systems Design Approach*. Chelsea Green Publishing, White River Junction, Vermont.

Ferguson, R. S. (2014a). Toward 21st century permaculture: Peoples science or pseudo-science? *Permaculture Activist*.

Ferguson, R. S. (2014b). Towards 21st century permaculture: Critical questions and early answers. *Permaculture Activist*.

Ferguson, R. S. and Lovell, S. T. (2014). Permaculture for agroecology: Design, movement, practice, and worldview. a review. *Agronomy for Sustainable Development,* 34:251–274.

Ferguson, R. S. and Toensmeier, E. (2014). Perennial agriculture now: A global review of perennial staple crops by climate region and nutrient profile. Presented at the *American Society of Agronomy International Annual Meeting: Great Challenges, Grand Solutions*, Long Beach, CA.

Flores, H. C. (2006). *Food Not Lawns: How to Turn Your Yard into a Garden and Your Neighborhood into a Community*. Chelsea Green Publishing, White River Junction, Vermont.

Fukuoka, M. (1978). *The One Straw Revolution: An Introduction to Natural Farming*. Rodale Press, Emmaus, PA.

Hemenway, T. (2009). *Gaia's Garden: A Guide to Home-Scale Permaculture*. Chelsea Green Publishing, White River Junction, Vermont, 2nd edition.

Hemenway, T. (2015). *The Permaculture City: Regenerative Design for Urban, Suburban, and Town Resilience*. Chelsea Green Publishing, White River Junction, Vermont.

Hirtz, J., Stone, R. B., McAdams, D. A., Szykman, S., and Wood, K. L. (2002). A functional basis for engineering design: Reconciling and evolving previous efforts. *Research in Engineering Design*, 13:65–82.

Holmgren, D. (2002). *Permaculture: Principles and Pathways Beyond Sustainability*. Chelsea Green Publishing, White River Junction, Vermont.

Holmgren, D. (2002). *Future Scenarios: How Communities Can Adapt to Peak Oil and Climate Change*. Chelsea Green Publishing, White River Junction, Vermont.

Hopkins, R. (2008). T*he Transition Handbook: From Oil Dependency to Local Resilience*. Chelsea Green Publishing, White River Junction, Vermont.

Jacke, D. and Toensmeier, E. (2005a). *Edible Forest Gardens: Ecological Design and Practice for Temperate Climate Permaculture*, volume 2. Chelsea Green, White River Junction, VT.

Jacke, D. and Toensmeier, E. (2005b). *Edible Forest Gardens: Ecological Vision and Theory for Temperate Climate Permaculture*, volume 1. Chelsea Green, White River Junction, VT.

Jones, P. H. and Upward, A. (2014). Caring for the future: The systemic design of flourishing enterprises. In *Proceedings of the Third Symposium of Relating Systems Thinking and Design (RSD3)*, pages 1–8, Oslo, Norway.

Lescourret, F., Dutoit, T., Rey, F., Cote, F., Hamelin, M., and Lichtfouse, E. (2015). Agroecological engineering. *Agronomy for Sustainable Development*, pages 1–8.

Lovell, S. T. (2012). Agroecology. In Craig, R., Nagle, J., Pardy, B., Schmitz, O., and Smith, W., editors, *Encyclopedia of Sustainability Volume 5: Ecosystem Management and Sustainability*, pages 11–16. Berkshire Publishing, Barrington, MA.

Mann, S. (2015). *Interview with Rob Scott*. The Permaculture Podcast, www.permaculturepodcast.com.

Mitsch, W. J. (2012). What is ecological engineering? *Ecological Engineering*, pages 5–12.

Mollison, B. (1979). *Permaculture Two: Practical Design for Town and Country in Permanent Agriculture*. Tagari, Stanley, Tasmania, Australia.

Mollison, B. (1988). *Permaculture: A Designers' Manua*l. Tagari Publications, Sisters Creek, Tasmania, Australia, 2nd edition.

Mollison, B. and Holmgren, D. (1978). *Permaculture One: A Perennial Agricultural System for Human Settlements*. Tagari, Tyalgum, New South Wales, Australia.

Odum, H. (1971). *Environment, Power, and Society*. John Wiley and Sons, New York, NY.

Rudolf, P. and Kingsbury, N. (2013). Planting: A New Perspective. Timber Press, Portland, OR.

Papanek, V. (1984). *Design for the Real World: Human Ecology and Social Change*. Academy Chicago Publishers, Chicago, IL, 2nd edition.

Rutter, P., Wiegrefe, S., and Rutter-Daywater, B. (2015). *Growing Hybrid Hazelnuts: The New Resilient Crop for a Changing Climate*. Chelsea Green Publishing, White River Junction, Vermont.

Scott, R. (2010). A Critical Review of Permaculture in the United States. Self-published, http://robscott.net/2010/comments/, as retrieved Nov. 28, 2015.

Shepard, M. (2013). *Restoration Agriculture: Real World Permaculture for Farmers*. Acres USA, Austin, TX.

Simon, H. (1996). *The Sciences of the Artificial*. MIT Press, Cambridge, MA, 3rd edition.

Smith, J. R. (1929). *Tree Crops: A Permanent Agriculture*. Harcourt, Brace, and Company, New York, NY.

Sterling, B. (2005). *Shaping Things*. MIT Press, Cambridge, Ma.

Toensmeier, E. (2007). *Perennial Vegetables: From Artichoke to Zuike Taro, a Gardener's Guild to Over 100 Delicious, Easy-to-Grow Edibles*. Chelsea Green, White River Junction, VT.

Toensmeier, E. and Bates, J. (2013). *Paradise Lot: Two Plant Geeks, One-Tenth of an Acre, and the Making of an Edible Garden Oasis in the City*. Chelsea Green, White River Junction, VT.

Tow, R. (2003). Strategy, tactics, and heuristics for research: A structuralist approach. In Laurel, B., editor, *Design Research: Methods and Perspectives*, pages 135–142. MIT Press, Cambridge, MA.

Upward, A. and Jones, P. H. (2015). An ontology for strongly sustainable business models: Defining an enterprise framework compatible with natural and social science. *Organization and Environment*, pages 1–27.

Wolz, K., Mattia, C., Revord, R., Nelson, D., Eisnhardt, E., Kranz, A., Branham, B., Wander, M., Dalling, J., DeLucia, E., Shepard, M., and Ellis, J. (2015). *Woody Perennial Research Site: Large Scale Research on a Savanna-Based Agroecosystem*. http://wppresearch.org/ as retrieved on November 1, 2015.

Yeomans, P. A. (1958). *The Challenge of Landscape: The Development and Practice of Keyline*. Keyline Publishing PTY. Limited, Sidney, Austrailia.

Yeomans, P. A. (1981). *Water for Every Farm.* Second Back Row Press, Leura, Austrailia.