Solving for pattern: an ecological approach to reshape the human building instinct

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Abstract

The human species' adaptive advantage is driven by its ability to build new material structures and artifacts. Engineering is the modern manifestation of this building instinct, and its advent has made the construction and use of technologies the central pattern of human life. In parallel, efficiency, the overarching narrative driving technology and related life practices, has pervaded most occupations as a value, forming a cultural backdrop that implicitly guides decisions and behavior. We examine the process through which this backdrop has developed, and argue that it emerged through the constant presence and use of built artifacts and structures, which function as manifestations of the engineering value of efficiency. The constant presence and use of built structures leads to the slow percolation of their building values into society, forming a cultural narrative of efficiency. This narrative then feeds back, to further reinforce the engineering processes driven by efficiency. This loop creates a runaway building system that is highly resistant to change, even when faced with the prospect of the species going extinct. Any effort towards sustainability can be successful only when this all-pervading – and hence invisible – building loop is made explicit, and compensated for, through a counter-loop where building manifests sustainable engineering values. As a first step in revealing this structure, we characterise the emergence of the efficiency value as a cultural narrative, and analyse its wide-ranging environmental effects. We then present the design principle of 'Solving for Pattern' (SfP) as an illustrative contrast case. SfP, first articulated by Wendell Berry, focuses on interconnectedness and flourishing of all species as central design principles. We argue that these ecological principles can be extended to engineering, and can thus support the development of a robust operational-level building movement that manifests value systems oriented towards sustainability. To ground this proposal in actual practice, we outline two case studies of technology design that illustrates SfP. We also discuss three cases that illustrate SfP at a larger scale, and examine how these extend existing design approaches such as systems engineering. We conclude with a proposal to include SfP in engineering education curricula, to facilitate a faster cultural shift towards flourishing, which is required given the limited time-window available to move to sustainable building practices.

Keywords: building; reshaping, efficiency; solving for pattern; process-model, education

Introduction

The impact of human actions on the planet have prompted geologists to term the present era the 'Anthropocene'. Most human actions that are changing the plant revolve around building new structures in the environment. The ability to change environmental structures for better chances of survival (which we term the 'building instinct'[1]) is commonly seen in many species, including insects (Mhatre and Robert, 2017). Niche construction theory (NCT) argues that all organisms have the ability to modify their environment, in order to manage evolutionary pressures (Kendall, Tehrani, and Smee, 2011; Albuquerque et al, 2017; Laland, Odling-Smee, Feldman, 2000). Since the building of structures in the environment by other organisms has not led to the levels of environmental damage the planet is currently facing, the destructive potency of human building does not stem from the process of building itself, but from socio-cultural and psychological narratives that feed back into niche-construction behaviours, which have transformed the building instinct into a maladaptive and runaway process that is threatening the life-sustaining capacities of the planet (Ellis, 2015).

There is now broad consensus that radical changes in our building behaviour is needed to avoid ecological collapse (Hoegh-Guldberg, 2007; Hunt and Watkiss, 2011; Reese 2010). Given this understanding, there are only two ways forward. One is to stop building. This is unlikely to happen, given the centrality of building to human existence. The second is to try to build ourselves out of this dire situation. This requires reshaping the building instinct, such that it now works: 1) to support the flourishing of the biosphere, and 2) to remediate existing ecological problems. Current discussions on sustainability do not consider such an active program to reshape the building instinct this way. Most current actions oriented towards the environment (such as creating non-fossil fuel technologies, developing recycling systems etc.) are based on building, but these approaches do not actively seek to *reshape the building instinct itself*.

Such a reshaping would be similar to other historical cases where biological instincts have been reshaped. For instance, the reproductive instinct (the drive to produce offspring) and the territorial instinct (the drive to attack conspecifics who enter your habitat), have been reshaped by humans, using technologies such as birth control (reproduction) and property law (territoriality).

1 *The term 'instinct', as used in the context of this paper, implies a broader meaning than a fixed, innate, biologically hard-wired behavioral pattern. In this paper, it refers to the human species' adaptive advantage driven by its ability to build new material structures and artifacts. Engineering is argued to be the modern manifestation of this building instinct, now in a runaway mode. The current maladaptive building instinct is understood to stem from cultural narratives generated over time. We discuss and elaborate on this notion/argument in Section 1 of the paper.*

These instincts have been reshaped by technological and cultural developments, in an implicit fashion (i.e. without explicitly seeking to reshape the instinct). However, the reshaping of the building instinct needs to be more intentional and active, given the limited time window available to move to sustainable alternatives.

Three inter-related questions emerge once the reshaping of the building instinct is explicitly considered as an intervention possibility. One, how did building become a runaway instinct, generating inherently unsustainable processes? Second, given a way of understanding the emergence of this runaway process, what could be an alternative building approach? Third, what is an operational way to implement such an alternate approach? In this paper, we seek to propose an overarching model that answers these three questions in an integrated fashion.

To address the first question, we propose a process account, where a feedback loop between psychological processes (interactions with built structures) and social structures (value systems that emerge from the interaction with built structures) lead to the idea of efficiency becoming a dominant criteria for designing technology (Section 1). This analysis suggests that alternate ways forward would need to compensate for this feedback loop. For instance, a building approach that is driven by ecology, rather than *just* efficiency, could lead to built structures that manifest ecological values, particularly flourishing of the biosphere. We illustrate this proposal by extending the idea of Solving for Pattern (SfP) – first proposed by Wendell Berry – to building processes, proposing it as an ecological framework for building (Section 2). We argue that SfP can be adopted as an engineering design principle, to develop large scale projects characteristic of contemporary engineering (Section 3). We conclude by suggesting that the incorporation of SfP in engineering education for sustainability could be an operational way to quickly move towards sustainable building. Such an approach to engineering education would help accelerate the formation of cultural narratives that support designs oriented towards the flourishing of the biosphere (Section 4).

The primary objective of the paper is thus to understand building and its effects from behavioral and process standpoints, and propose a *process model* for engineering pedagogy that could help change building behavior, based on biological and ecological perspectives. The focus is on developing an *operational* way to change both current building behavior and its associated cultural narrative.

1. The runaway building instinct

Research in cognitive science has argued that science and technology practices are based on cognitive capacities that are refined versions of everyday capacities (Nersessian, 2010). This view, and the fact that building based on science and technology is evolutionarily very recent, suggests that recent building behavior is biologically not very different from older building and niche construction behavior. It is thus very likely that the ecological damage generated by contemporary building emerges from social, cultural and psychological factors, interacting closely with the building instinct.

Many thinkers have pointed out that our current maladaptive building instinct stems from cultural narratives that have developed over time. Capra (1982) argues that scientific and technological production does not just constitute the fabric of the society, it has also shaped cultural perceptions about the right way to live. In the words of William Rees, "matters are complicated by the fact that our dominant cultural narrative, the growth-based progress myth, reinforces our now disadvantageous behavioral predispositions"(Rees, 2010: 20).

One way to understand the role played by cultural factors in changing building behavior is to examine, from a process as well as biological/ecological perspectives, the shift from older building practices to the currently dominant one. For instance, extending the biological principle of form following function, we can consider the practice of building – engineering / designing of any technology – as manifesting its values (such as efficiency) in the technology it creates. This leads to the engineering design principles embedded in the technology to be enacted in its use.

Once so manifest, physically and through enaction, the technology becomes a constant part of society, through both perception and action. A constant human-technology interaction is thus created, which leads to three related processes. One, it allows the values of design and practice, which are manifested by the technologies, to seep into each individual's understanding and behavior. Second, this gradual process eventually leads to an overall cultural narrative (such as the efficiency narrative) that reflects these embedded values. Third, once formed, this cultural narrative loops back, to reinforce the same engineering values underlying the designs. These processes together create a powerful positive feedback system, which both reifies and expands the existing technology design principles (See Fig 1). This process is similar to the development of cognitive control through tool use, which is analysed in detail by Vygotsky (1980).

Fig 1. A generic representation of 'building' technology and the values it is guided by gets reified.

Note that this process perspective is generic. In this view, craft – the traditional practice of building based on limited and biological resources available locally – also manifests a value system. Apart from functionality, the reuse of natural resources (as well as repair and recycling) were key components of such craft, as the practice required the continuing availability of these resources,. The design practices of the skilled artisans, passed on through apprenticeship, depended on the immediate environment, and therefore valued and conserved it. Their practices were thus inherently restrained and sustainable, and the artifacts and practices manifested these design principles, which were then imbibed by society. These were then reflected in the larger cultural narrative, which was oriented towards sustenance and frugality. (See Fig 2).

Fig 2. The traditional building practice embedded values of sustenance.

The origins of the term 'technology' reflect this history. It is derived from two Greek words – *tékhne*, which refers to the skill of craftsmanship, and *logos*, suggesting the application of reason. Traditionally, 'technology' is thus closely tied to the technique possessed by an artisan, and governed by sensibilities emerging from interactions with the immediate surroundings. The practices involved in traditional crafts, learned through apprenticeship, focused on necessities and livelihoods. This approach embedded frugal, animistic ways of living, and thus tended to be ecologically sustainable by default (Ingold, 2013).

The modern practice of engineering harnessed much bigger sources of power (such as steam) than human and animal power, first through industrial processes (such as the steam engine), and then through symbolic models (such as thermodynamics and electromagnetism) that abstracted away from particular industrial processes (Ihde, 2000), and thus allowed imagining and recombining the industrial processes at far larger scales. These interconnected representational and artifactual building processes together allowed building highly scaled technological systems, using resources from across the globe (Alvares, 1980; Bennet, 2017; Baumard, 2018). These resources in turn became more accessible through the same scaling processes (such as building of big ships). Since scaling also increased available resources – when one resource was exhausted, another could be found – the design process changed from being need-driven to being technology-driven.

A key factor driving the scaling was the level of output based on given inputs (efficiency). Cost – a construct that helps optimize the efficiency and scaling requirements – thus became a key constraining factor. This led to design practice becaming guided by technical efficiency (output to input ratio) and cost, and built artifacts made manifest these design values. Once so manifest, these values seeped into society, turning efficiency and cost into cultural values. These cultural values then fed back into the industrial processes, promoting automation and centralization of production, in order to achieve 'economies of scale' – which is the optimisation of the efficiency-cost combination at the level of business processes, and the economy. The resulting mass production required finding markets beyond local users. Combined with the centralization of production, the new and large markets led to a concentration of wealth. The expansion of both the resource-base and the consumer-base then became a process by itself, leading to a narrative of abundance, opulence, and unchecked consumption, in contrast to the earlier one of restraint.

As technology became all-pervading, manifesting these and other related design values, the cultural narrative adopted efficiency as a central value, always seeking 'more for less'. (See Fig 3). The reinforcing feedback loop based on this, and related values, created the runaway practice of constantly building and buying technology to increase efficiency. This runaway process has led to ecological and social damage at a corresponding global scale.

The contemporary narrative of technology can thus be understood as promoting systems unlimited by context, which allows technology to be applied widely, to gain control and power over the environment (Ellul, 1964; Mitcham, 1994; Winner, 2010). This narrative is based on, and promotes, a separation of technology from its social and ecological relations. This separation has created a disembodied process, concerned with singular goals. Ingold makes this point clearly:

> "The modern semantic shift from technique to technology, associated with the ascendance of the machine, is itself symptomatic of the disembedding of the forces of production from their social matrix, transforming the correspondence between forces and relations of production from the internal to the external, and setting up the now familiar opposition between technology and society." (Ingold, 2000: 318)

Fig 3. The modern formal engineering practice where efficiency is a key value.

The next three sub-sections examine this 'efficiency turn' in more detail, from three perspectives: design, narrative and sustainability.

1.1 Efficiency as a wider design principle

Smith (1969) contends that the focus on efficiency, and the resultant economic benefits, creates crucial differences between traditional activities such as weaving or pottery, and their modern counterparts such as textile and ceramic engineering. Carl Mitcham (1994) comments that idealizing efficiency as a parameter lowers the effort required in engineering design, which in turn systematizes the efficiency bias.

Efficiency is technically defined as 'a ratio of outputs to inputs' and expressed in terms of percentages. In a historical analysis of the concept of efficiency, Alexander (2008) describes the 20th century view of efficiency as a formal standard, to measure the internal economy of a machine. Efficiency also plays a calibration role, enabling comparisons between machines or systems of widely different designs and functions. Over time, maximizing efficiency, through 'as perfect a correspondence between output and input as possible', has become a goal in itself for machine design.

There is nothing inherently wrong in striving for the least wastage of economically valuable inputs while achieving technological outputs. However, the *priority* given to this sole parameter, particularly in selecting between different technologies, has led to damaging consequences.

A revealing example is provided by Claude Alvarez (1997), who describes how the sugar industry moved from production of jaggery (raw sugar obtained by evaporating water from sugarcane juice) towards white sugar, because of the higher extractive efficiency of the latter. This shift came with a cost – energy-intensive methods and environmental pollution (which is nearly absent in the jaggery making process). Further, the more 'efficient' process of extraction delivers a product (white sugar) which is stripped of all nutritional value, and a negative impact on health. However, “whether it is worth producing a commodity that is harmful to human health and also damages the environment (waste heat and effluents) is not part of the efficiency debate” (in Sachs, 1997: 223–224).

A similar damaging design shift is the recent focus on occupancy rates and luxury in hospitals, where throughput and value-addition – efficiency measures borrowed from the hotel industry – replaces the cardinal medical values of curing and caring of patients and their health. Efficiency has thus become an obsessive value by itself, to be achieved by creating pointless products and services that cost human health and ecological destruction.

1.2 Efficiency as a cultural narrative

This shift, from a mutual, reciprocal relationship between the artefact, environment, and the craftsperson, to mechanistic, exploitative and consumption-driven industrial processes, has led to parameters of technological production becoming social values. In particular, 'efficiency' is a parameter that has now turned into a social goal by itself (Alexander, 2008), thus turning disembodied technology into a value system – efficiency is now the measure of humans and nature.

Feenberg (2002) comments that technical disciplines are fundamentally oriented towards creating efficiently-functional devices, and this process systematically abstracts away the social dimensions of the activities, which are then considered to be the domain of humanistic disciplines. The preference for functional and technical efficiency then translates into economic efficiency, particularly economies of scale provided by assembly lines and industrial production. This multilayer structure (functional, technical and economic efficiency) has created a set of professions and practices that organise social structures based on the default engineering perspective, which has also become the dominant value system of mainstream industry. In this currently dominant narrative, industrial practice strives towards achieving optimality, based first on technical (functional) performance, and then on profit, which is operationalised as mass production for economies of scale. Technology is designed and optimized for this narrow industrial context, rather than the larger societal context, which is the environment that the technology is embedded in, and is expected to serve.

The focus on performance optimality ('More for Less') thus acts as a gateway and stand-in for a value system, where profit is the central design norm and virtue, and other notions of optimality (such as social and ecological) become aberrations. In the process of achieving the primary objective of techno-economic efficiency, the abstracted socio-ecological ends are automatically neglected or sacrificed. As Derrick Jensen points out, “Our economics, as is true of our science, represents the triumph of product over process, and form over content. It is triumph of selective deafness and blindness over conscience and relationship” (Jensen, 2004: 140).

Vandana Shiva (2016) argues that reductionist perspectives validate the circular logic of internal efficiency, by selectively accounting of products and resources, so that it seems that exploitation and extraction generate profits. This often happens by externalizing non-commercial or unaccountable parts of an ecosystem. When this approach becomes standard industry-wide practice, associated values become a part of the larger socio-cultural fabric of a society. Similar value systems and vocabulary, emphasizing 'output', 'performance' and 'standardisation' as virtues of a smooth-functioning system, has long found its way into the enterprises of education, management, and medicine (Good, Aronson, and Inzlicht, 2003; Kim, 2005; Sahney, Banwet, and Karunes, 2004). The dominance of efficiency-driven modern technology thus helps reduce all problems and their solutions to mere input-output ratios. This perspective oversimplifies complex ecological and social dynamics that are involved in every design into linear cause-effect relationships, leading to system designs that corrupt the entire pattern of relationships they are embedded in.

Architect Christopher Alexander conceptualizes the challenge to counter the efficiency narrative as a battle between two world-views; one based on the principles of arbitrary regulations, atomistic assumptions, and procedures, while the other is “governed by human judgments that emanate from the underlying wholeness” (2012: 49). He sees conventional urban buildings as manifestations of the reductionist world-view, designed to be efficient in terms of cost, housing, construction time etc. But the process of such building is blind to the ecosystem it is embedded in, and the design specifications do not provide criteria such that the buildings seek to support and enhance the life around them.

Postma contends that the narrative of efficiency reduces human activity to a cost-benefit analysis, thereby devaluing intrinsic aspects of the work involved. "Within this type of rationality, the sole activity consists of looking for the most efficient means to given ends. Human activities are not valued in terms of intrinsic worth, but judged by reference to the balance between costs and benefits. For the most part, the ends and benefits are given with the quasi-neutral 'needs' that are prevalent within the existing economic and political structures and power relations (2006: 142)."

1.3 Efficiency in the sustainability discourse

In recent times, the aims of technological interventions have shifted to achieving ecological sustainability. However, the underlying values driving technological design have not been questioned systematically. For instance, in the context of energy-use, Zehner (2012) points out that the push for seemingly 'clean' energy sources, or 'better' ways to extract fuel, are simply assumed to be right, without delving into more fundamental issues of consumerism, waste, and disruption of community cohesion that would question the energy need as a primary requirement. Instead, the decisions seem to reduce to efficient ways of extracting and using the resource.

> "Energy rhetoric in the United States has largely devolved into arguments pitting *productio*n versu*s productio*n in manufactured pseudodebates that fool us into thinking that we are making genuine energy choices. The only reason these appear to be reasonable comparisons is that we are so deeply immersed in the dirt fossil-fuel way of life that a less less-dirty bad idea can seem good. (The rise of petroleum itself was seen initially as an environmental benefit as it slowed the extermination of whales for their oil) (2012: 334)."

In fact, the approach to 'sustainable development', which hinges on techno-centric claims of efficient use of natural resources, has been widely critiqued as a fallacy, due to its inability to question the premises underlying development (See Bonnett, 2013; Huckle and Wals, 2015; see Lele, 2013 for a detailed discussion). For instance, given the way technology and built systems are rapidly destroying the biosphere and corroding human relations, the question of "should this technology be made" needs stronger justification than the operational premise of efficiency.

While some continue to put faith in the current model – such as by trying to build technology to inhabit outer space, and arguing that current efficiency-driven technology will eventually solve all the problems they have created – the above-sketched evolution of this mode of human existence, and the rampant damage it has generated, suggests that this is not the direction towards sustainability. A more productive approach would be to try to reshape this current configuration of the building instinct, such that building supports the flourishing of both ecology and society. This reshaping requires drastic changes in engineering design practice and principles, the manifest technologies, and associated cultural narratives.

Such a reshaping is very difficult, as shifting away from the default model, of 'existence as making and consuming of technology', requires making explicit, and questioning, the deep-rooted and implicit assumptions about our relationship with nature and technology, such as the model of "conquest of nature". Going further, developing an alternative path requires unearthing the process by which deep-rooted technological value systems have come to undergird and encourage our present lifestyle, and implementing technology design processes that embed alternative value systems, which respect and promote the ecological interconnections that sustain us. This task is particularly difficult because there is no contrast model available, to compare and understand this currently dominant model of existence.

The required shift is thus not just a technological one, but also a cognitive, behavioral and cultural one, where we need to develop the ability to clearly see the technological 'water' that both sustains and binds us, and then use this understanding to completely reimagine the relationship between humans and the environment. In particular, we need to reject the model of environment-as-a-resource, and adopt an alternate model where our success depends on promoting the abundance of biodiversity and natural ecologies. The next two sections sketch such a possible model.

2. Solving for pattern: a possible way forward

The efficiency-driven engineering approach has created the current hyper-connected economy, which is built on several layers of disconnect between the land, technology, and the people, and damages the life-sustaining capacities of the planet. Bonnett (2013) argues that the "arrogant instrumentality" of the Cartesian paradigm, which perceives the world as just a goody box of resources, is a key driver of this disconnecting process. He argues that such a discursive ontology gives way to an "essential blindness", which impoverishes our relationship with nature. Several scholars have argued against the Cartesian disembodied perspective towards the environment, calling instead for embedded and embodied interactions with nature (Bonnett, 2007; Iared, de Oliveira, and Payne, 2016; Payne, 1999a; Rathunde, 2009). Authentic building experiences that highlight a participative relationship with the environment are crucial in correcting this direction, to establish mutual dependency as a central value system (Bai, 2015; Davis, Green, and Reed, 2009; Zylstra, Knight, Esler, and Le Grange, 2014).

The traditional vocation of farming is perhaps one of the oldest ways to practice this perspective of mutual sustenance. Philosophers have used soil as a metaphor to discuss many environmental virtues (Esteva and Prakash, 2014; Prakash, 1994), but perhaps few other than Wendell Berry have used farming as a way to argue for the pragmatic necessity of acknowledging and working within a complex ecology, to practice building in ways that contribute to the flourishing rather than control of the biosphere. Berry proposed the term 'Solving for Pattern' to critique the narrow problem-solving, efficiency-oriented approaches of industrial agriculture. His commentary, however, highlights some of the core problems with the general technocratic, efficiency-centred approach to building. According to him, technology that is based exclusively on the efficiency perspective may turn out to be a 'bad solution', because,

> '... it acts destructively upon the larger patterns in which it is contained. It acts destructively upon those patterns, most likely, because it is formed in ignorance or disregard of them. A bad solution solves for a single purpose or goal, such as increased production. And it is typical of such solutions that they achieve stupendous increases in production at exorbitant biological and social costs' (1981: 136).

Efficiency-oriented technological solutions work within limited parameters and designed outcomes, which characterise the world in terms of manageable categories that need to be optimised. Berry is critical of this approach, because it dismisses the inherent complexity and interconnectedness of human and ecological well-being. Furthermore, the embodied experience of participating in such practices implicitly generates values that are reductionist, modular, and transactional in nature (Dutta and Chandrasekharan, 2017). In his view, countering these values requires active engagement with practices that embed an integrative and interdependent understanding of ecological relationships. He calls this perspective 'Solving for Pattern' (SfP). SfP provides a good starting point for developing a model of building and design based on ecological relationships and situatedness.

It is worth noting here that SfP explicitly espouses ecological values, and thus differs from recent design approaches such as systems engineering, industrial ecology, and product life-cycle analysis, which draw on the engineering domain to design the solution landscape. As a result, trade-offs are the dominant theoretical construct in these frameworks. In contrast, SfP recommends restraint and reciprocation as the two guiding principles for designing good solutions. Berry argues that a good solution must engage with the idea of limits, not just as a theoretical maximum, but as a practical guide to sufficiency. A design based on SfP would resist adding changes just because they are possible. It would also not “solve” problems by ignoring them, or accepting them as “trade-offs". Reciprocation emphasizes respect for the complex interactions that sustain any ecosystem, with a focus on what can be 'given back', rather than be controlled. 'Giving back' in turn requires 'listening' to an ecosystem, through its various manifestations. It honours the unknown, as much as it appreciates the known parts of a system.

Such *epistemological humility* (Bonnett, 2013) is typically missing from other recent design perspectives, which primarily aim for predictability and control, to maximise output, though more parameters are now included in the calculation. An approach such as SfP highlights the need for sensitivity, respect, and the capacity to trace ecological patterns, particularly when building technologies. The way to sustainability can emerge only through entering into a responsible relationship of reciprocation with nature, which is fundamental to ecological patterns, rather than plundering, polluting, and controlling nature through technology. The reciprocation approach to design aims to preserve the wholeness or integrity of a system, which makes SfP an ecological value, quite distinct from input-output efficiency, and its various recent 'green' forms.

The challenge lies in developing a narrative of human building, enterprise and existence where such reciprocity is the central feature. This requires bringing to the fore, and celebrating, experiences that nurture a sense of place, as well as an understanding and appreciation of non-human actors and agencies, such as microbial systems and weather patterns, and their inter-relations, such as the rich connections of mycorrhizal networks (Giovannetti et al., 2006; Singh, Bardgett, Smith, and Reay, 2010). Rebecca Martusewicz (2005) terms such reciprocal participation within communities as 'collaborative intelligence', in contrast to artificial dichotomies and rationalisation based on standard engineering categories. This approach creates a rootedness, which allows for an appreciation of multiple layers and interconnections. Engagement with such practices allows for an ethic of generosity and care, and sustainability is a natural outcome of the process.

For example, while describing the issues of forest conservation, Berry writes, "A good forester thinks first of the forest … A bad logger goes to the woods thinking of what he can take out. A good logger goes to the woods thinking of what he should leave. It is this generosity towards forest that enables the necessary thought" (2015: 47). There is thus a certain deliberation and attention demanded within the SfP perspective, which is uniquely tied to the context.

Fig 4: An illustration of possible SfP design practices, embedding principles of interdependence, reciprocation and restraint. The artifacts and interactions so generated would help reinforce such design practices and larger cultural narratives.

3. Solving for Pattern in practice

To illustrate the theoretical arguments made so far, we briefly describe two case studies where a narrow efficiency-driven approach to design is expanded, to include wider considerations of social and ecological relationships and reciprocation, demonstrating 'Solving for Pattern'. The first case discusses the practice of grassroots design of a micro hydro power system (for details see Date and Chandrasekharan, 2016), the second outlines behavioral changes related to the practice of growing food in an urban community terrace farm (for details see Dutta and Chandrasekharan, 2018).

3.1. Case 1: Construction of micro hydro power systems

EP (pseudonym) is a trained civil engineering professional, who has been designing and building micro hydro power systems in remote mountain regions of India, such as the Himalayas. Tough terrain, harsh weather conditions, dispersed and remote population, and poor load characteristics aggravate the challenges and cost of providing reliable grid-based power to such regions. On the other hand, Micro Hydro Power (MHP) systems address this unmet need, by utilizing the naturally available mountain gradient and perennial water streams to generate power locally, in the range of 1-100 kW. Over several years of developing such MHP systems, EP's design practice and principles have evolved.

In one of his early projects, as a consultant to an NGO, EP built a micro hydro power station to provide hydro electricity to tribal villages in a reserve forest area in the state of Odisha, India. The characteristics of the source - a waterfall about two km from the villages - indicated two technical options for the type of turbine, either a 'pump as turbine' or a Pelton wheel. The 'pump as turbine' option was less expensive and widely available. But it could accommodate only one flow rate and its efficiency was low. A Pelton wheel on the other hand can handle variations in flow and high head.

Considering the seasonal variation in the input flow, EP provided two alternators, generating 10 kW for low flow and 25kW for high flow. The power could support two bulbs, one tube light, one plug-point, one fuse, and one isolation switch in each household, as well as ten streetlights in the village. To manage the variation in electric load, EP designed a Digital Load Controller (DLC) and each house was fitted with a variable load controller with manual reset.

Although technically sound and running, the power generation ran into issues, and had to be halted for lack of maintenance, because the villagers did not contribute to the corpus of funds necessary for maintenance of the system. This occurred because the design did not put enough emphasis on developing the community's stakes (Vaghela, 2006). As the sophisticated Pelton-type turbine had to be fabricated in a big city, the community had no experience handling technical issues related to it, even though the NGO had intended for the maintenance to be handled by the community. In later projects, the NGO emphasized training local people to fabricate the turbines locally. Hurdles of this nature were also identified by EP, as he commented,

> *"And similarly control systems are again all electronics based control systems. Something goes wrong in control system, you are in trouble, you have to go down [to the plains].*"

With such experiences, EP reconsidered his choice of some of the components and modified his power station design for subsequent projects, starting from the point of view of ease of fabrication, installation, and maintenance, in the context of the users and conditions in the remote mountain villages. Based on this, EP suggested that,

> "*... we should make equipment in such a way that can be opened easily. So there had to be some change in it. Every time we used to think which part umm, you know, is difficult to remove, and simplify it actually...*".

For example, where he could work with a low head of water, he opted for a cross flow turbine. A cross flow (Banki or Ossberger) turbine, is simpler to design, fabricate, and maintain. "Though less efficient, its simpler structure is less expensive than other low-head turbines of the same capacity. Since the water flows in, then out of it, it cleans itself and is less prone to jam with debris" (Micro hydro, 2016).

Later EP was entrusted with a UNDP-funded project in the Himalayan region that included a livelihood support component along with micro hydro power development. EP designed a micro hydro system where part of the time the drive was used to generate electricity for the village. At other times, when electricity was not required, it was used to provide a mechanical drive, to run various machines supporting livelihood activities based on processing of local resources, such as wool. EP commented that,

> "*... after doing the project it was a very big realization that unless people are making money out of that, you can never run this power station. But if they are able to make money out of it, it is the best scheme actually. There is no other scheme you know that is better than this hydro power. ... If you can make people just self-sufficient by this, it's the best thing you can do.*"

EP now roots for micro hydro power over all other alternatives. Contrasting this approach with the mega power stations, he points out the need for choosing technology that leads to sustainable development, balancing both environment and human needs. EP points out that,

> *"... if you go to non-renewable energy ministry, they will say we are interested in mega watts, or high generation of power. But they don't realize even small generation can benefit the village, you know, in a very big way."*

He also does not take up projects without addressing community needs. This perspective is a categorical shift, brought about by years of practice that taught him to design with the network of larger patterns in mind, such as the ecological and the social, with technical efficiency just working as one of the factors. EP's key design changes across different projects are interconnected in his person, and these changes have turned into a value system that is different from the efficiency one, and is close to the idea of Solving for Pattern.

3.1.1 Discussion: EP's approach of optimizing for a network of patterns

A singular focus on techno-economic efficiency would lead to generating maximum electricity at the lowest cost. But sustainably addressing unmet needs of people at the grassroots, through designing technology, requires an engagement with other components of ecology and society.

As a trained engineer, EP could have regulated the quantity of water throughout the year by storing it in a reservoir, instead of suffering seasonal variations by directly drawing water from the source (waterfall). But EP did not opt for controlling the input conditions by storing water in dams. Instead, he provided a Pelton wheel that could run two different generators that provided higher or lower power output, depending on more or less water supply seasonally.

His knowledge of traditional water mills that draw water from the streams directly, as well as a budget constraint, led to this design preference. But this decision was good for ecological sustainability, because it led to lesser interference with the ecosystem of the waterfall, which does not exist to support just humans (as would be suggested by classical design practice), but many other forms of life with niche habitats and a web of interdependencies.

In subsequent designs, EP replaced the sophisticated Pelton turbine with a more sturdy Crossflow one, even though it is less efficient. In doing so, he traded higher power production for the community's convenience of maintaining and repairing the system. In remote areas, this would be a 'better' solution, because the community would now be able to keep the power system running at all times, and produce enough power, rather than have maximum power (technical efficiency) at the cost of a lot of downtime when the system breaks down. Furthermore, instead of hiring trained external help to run a power station, EP invested time in training 'barefoot engineers'. This ensured that the local community was self-sufficient as well as gainfully employed. The solution achieved better efficiency as an entire system, maximizing the benefits and minimizing the costs for the various 'stakeholders' and their network of connections or interdependencies.

In contrast, the solution of building mega dams to generate power significantly undermines the goals of social equity and ecological sustainability, in pursuit of purely technical efficiency. At the source end, water streams 'dam'ed into large, expensive, and biologically dead storages create adversities for local people, flora, fauna, and even geological structures. At the distribution end, transferring centrally generated power over large distances incurs losses. While it services big industry, this power completely bypasses small, remote villages. In terms of these larger patterns, such technology ends up being a bad solution. EP's designs, in contrast, are now guided by an approach that has emerged from the knowledge of, and respect for, larger (ecological, social, political, economic) patterns and connections that the technology is embedded in, beyond merely the technical.

3.2. Case 2: Cultivation of food in an urban setting

An urban terrace farming group (UF) started cultivating vegetables, fruit, and agricultural produce in the cosmopolitan city of Mumbai, through participatory activities of volunteers who gathered once or twice a week. UF was founded by Pushpa (pseudonyms have been used), a catering officer in a government institute. Her interest in farming began from the issue of disposing bio-degradeable waste generated by her canteen. She began experimenting with composting, and gradually began to use the compost to grow vegetables on the canteen terrace. Encouraged by the results, Pushpa, along with a few other environmental activists, began a volunteer driven movement to start terrace farms at different sites in the city. Most volunteers joined the farm for personal reasons, such as interest in outdoor activities, aesthetic appeal of flowers, wanting to design activities for their children, nutrition that is offered by fresh harvest, childhood experience of growing vegetables in the backyard, and so on. In other words, initially they didn't share the larger ecological motivations espoused by the founders of the urban farming group. Over the course of several weeks of this work, the volunteers' motivations evolved, to encompass wider environmental concerns. Volunteers reported particular tasks on the farm as drawing their attention, and subsequent concern, to phenomena they were otherwise unaware of.

As one of the central activities at the farm, the volunteers helped create *Amrit Mitti*, a microbe-rich soil, nutritious with high carbon content, and excellent water holding capacity. The process involved decomposition of dry biomass using *Amrit Jal*, an organic accelerator made of water, cow urine, cow manure, and organic black jaggery. The following comment from Payal describes her thoughts on soil, after working with *Amrit Mitti* on the farm:

"I didn't think about soil at all. Never thought about soil. It was all about compost … after doing the Save A Leaf campaign, trying to understand the chemistry and whatever, doing all this, I have a better understanding of soil. And you can make out when you see the difference, like the other day when we were repotting, the bottom soil was red earth, it was hard and soggy, clayey actually, so the roots could not grow. Soil needs fertility, it needs structure and it needs microbes. So that red earth didn't have structure, it didn't have carbon for aeration and all that. So it didn't have microbes … This is not something I knew 2 years ago. You are learning the significance every day."

Making *Amrit Mitti* can address the problems of lack of fertility in soil, and excess of carbon gases in the air, while growing food in urban spaces. The practice of decomposing dry biomass ensures that the carboniferous matter goes back into soil, instead of being burnt and released into the atmosphere. Recent studies support the practice of using dried leaves to build soil by linking efforts of increasing soil carbon to the mitigation of climate change (Singh et al. 2010; Wilby and Perry 2006; Sanchez 2000). As volunteer Arun commented:

"I also made amrit mitti at home in tubs after the workshop. It was a great experience. Plants did thrive in that soil."

Cow manure contains many microbes that aid in decomposition while the urine has high amounts of ammonia, which creates an ideal ambiance for the microbes to multiply. Jaggery aids in fermentation. The method recreates the traditional village practice of keeping cows near the farm, thereby allowing a mutually beneficial relationship between the soil, farm produce, cows and the farmer. Volunteers needed to perform different actions like sourcing cow-urine, cow-manure and dry leaves in order to make *Amrit Mitti*, and these actions lent themselves to a 'coagulative' practice that captured an interdependent understanding of environment, such as the symbiotic relationship of livestock and a farm, as well as the need for biodiversity for a healthy ecosystem.

As Pushpa elaborated:

"*Our air, our soil and our food are so deeply interconnected. Our learning through our productive organic rooftop food farms, our experience with the nutrient and microbial-rich Amrit Mitti, made by using dry leaves and biomass in our surroundings, has opened our eyes to this wonderful resource of dry leaves, which today, we see being trashed in the city … Our UF community rooftop farms are lush green and great carbon sinks in this mega city today. Over the years, our volunteers* *have been collecting heaps and tons of dry leaves to make Amrit Mitti. The miracle of increased carbon in our soil, feeding the microbes and in turn our trees, blessing us with rich harvests is a dream realised on our farms*."

In contrast, with a focus simply on efficient food production, adding fertilizers and pesticides might result in a good yield, but this practice adversely affects the soil, microbes and the nutritional value of the food. Further, the run-off from such farms heavily pollutes water bodies, creating dead zones in seas. Farming artifacts such as *Amrit Mitti* embed an integrative approach to cultivation, and in the process provide a counter-narrative to the modular designs of large-scale monocultures. Making *Amrit Mitti* created in volunteers many wider associations that were otherwise systematically compartmentalized in an urban existence, neatly categorised in terms of production, consumption and waste disposal. Growing food thus breaks these neat and 'efficient' categories, and behaviors based on them, to create larger cycles, encompassing various forms of life, ranging from bacteria to food and cattle.

The volunteers' community-based activities, involving interactions with each other and the social, economic, political, and ecological aspects of cultivation, helped them move beyond merely harvesting maximum produce.

3.2.1 Discussion: UL volunteers' approach of aiming for resilience

A food garden, by virtue of its elements and their relationships, embeds many action possibilities, to understand principles (such as interdependence) and ideas (such as recycling) related to the environment. Volunteers at UF were not focused on just yield, as overall health of the soil, plants and other living organisms were part of their discussion and concern. The emphasis on organic methods of farming also made them sensitive to issues of pesticide and fertilizers being added to commercially available food, as they could experience the difference in the quality and taste of the food grown on the farm.

Soil came to be seen as a complex living entity, rather than a simple medium supporting plant growth, leading to a more dynamic understanding of plant growth based on recycling of nutrients and symbiosis of organisms. The emphasis on mulching led to active collection of dried leaves, subsequently sparking a campaign against burning of leaves that later took shape as a petition for right to clean air. Pest-predator relationships were often observed as markers of soil health at the farm, and the practice extended to being critical of artificial means of removing pests, along with a lived understanding of the importance of biodiversity. Values pertaining to frugality and re-usability were often highlighted in discussing inputs required to make soil beds, and other necessary infrastructure. The importance of having healthy seeds led most volunteers to get involved in seed saving, simultaneously developing a critical stance against GM seeds. The practices in the farm thus connected the act of consuming food to the conditions under which food is grown and brought to our plates. The practice thus implicitly led to a systemic way of thinking about the human-nature relationship – a value system.

These practices provide an interesting alternative to large-scale technology-driven monocultures that focus solely on harvest per unit area, ignoring: 1) the environmental problems associated with degraded soil quality, 2) diminishing biodiversity due to heavy use of chemicals, 3) dependence on fossil fuels to run farming operations and 4) transport the produce over large distances. Tidball and Krasny (2009) argue that community farming ventures demonstrate what can be termed as 'socio-ecological resilience', as they contribute to diversity, local knowledge, skills, and a lifestyle adapted to locally produced food, thus exhibiting characteristics of resilient societies. Industrial agriculture only aims to maximize yield per unit area, while farming practices such as that followed at UF give equal or more importance to wider aspects as well.

3.3. SfP implementations at a larger scale

Since micro hydro power projects are small in scale compared to mega dams, producing power only in the range of 1-100kW, and the urban terrace farms grow food in small quantities, it could be argued that the large requirement for power and food across the world demands far greater production than can be met by such SfP technologies. In our view, 'solving for pattern' (SfP) as a perspective and design principle is not limited to small scales, and both small and large scale technologies could be developed based on this principle. To illustrate this, three larger-scale examples of SfP are discussed below:

a) *The Cochin International Airport Limited (CIAL)* at Kochi, India, installed solar panels to generate about 12MW power, which successfully supports the entire airport's power needs. The solar panels were installed over an area of about 45 acres. CIAL then initiated an organic farming project over 3 acres of this land, in spaces between the solar panels. The water used to clean the solar panels is used for growing organic vegetable gardens next to the panels. The garden helps reduce the dust on the panels, and provides gainful employment to people who live near the airport.

The project helps CIAL make money (as they save on power consumption and feed excess power to the grid), and the expense of watering the panels is compensated for by the vegetable garden, whose produce is sold in the airport as well as in the market (Deccan Chronicle, 2016). This combination design has created a lot of goodwill for the airport as well, particularly in the nearby villages. In 2018, CIAL was awarded the 'Champion of the Earth' award by the United Nations (UN), in recognition of their efforts to generate sustainable energy (Times of India, 2018).

b) *The Sahara Forest Project* seeks to create a bigger version of the above design, with more focus on flourishing, as it is situated in a desert. Initiated in Jordan with Norwegian support, the project attempts to utilize seawater, concentrated solar power (CSP), and atmospheric CO2, to produce food and other biomass, fresh water, as well as energy in the desert. According to their calculations, "A single SFP-facility with 50 MW of concentrated solar power and 50 ha of seawater greenhouses would annually produce 34,000 tons of vegetables, employ over 800 people, export 155GWh of electricity and sequester more than 8,250 tons of CO2." (Sahara Forest Project, 2018a).

In the process, using moisture released from the green houses, the project supports re-vegetation of the surrounding land, thus restricting and reversing the process of desertification, triggered centuries ago by the Roman conversion of forests to farmland for food. The vegetation in turn reduces dust, and keeps the CSP mirrors clean. The SFP initiative aims to use restorative practices to reverse the trend of desertification through sustainable farming practices.

Selecting sites in low-lying areas, the project builds infrastructure to profitably bring seawater using gravitational force and electric pumps. The desert heat and CSP are used for evaporation of the seawater. The vapor provides humidity to the greenhouse vegetable crops, and superheated steam runs turbines to generate electricity for the operations. Evaporated seawater also provides fresh water for drinking, irrigation in the green house, and for cleaning the CSP mirrors. Unlike the conventional desalinization plants, where brine is put back in the sea, salts are recovered in this process. These minerals provide an alternative to mining of salts. A number of economic enterprises can be developed around this infrastructure, including cultivation of fast-growing biomass such as fish and algae in the salt water ponds, by harvesting the sun and sequestering CO2. This creates many skilled and unskilled jobs for local people.

This large scale project, illustrating a synergy of multiple environmental technologies to support flourishing, can be seen as a step in the direction of solving for pattern, where the large scale challenges of food, water and energy are addressed, by building on renewable resources, employing non-polluting processes, and achieving diverse outcomes, while also seeking to create conditions of flourishing in the desert. More importantly, the project is based on the understanding that environmental problems are interlinked, and therefore their solutions must also be designed in a manner that interlinks solutions.

Following an SfP design implicitly, the efficiencies of the technologies are valued for their multiple outputs, and not just the maximizing of any one. "The synergies arising from integrating the technologies improve performance and economics compared to those of the individual components. In addition to its commodity outputs of food, energy and salt, the system also provides global climate benefits by sequestering CO2 in the facility's plants and soils, and by pushing back the accelerating process of desertification through the revegetation of desert areas." (Sahara Forest Project, 2018b).

c) *BAIF's Wadi Project* is conceived and implemented in participation with tribal people by BAIF, a national-scale NGO in India. One of the authors has worked closely with this project for some years. It is primarily an integrated agri-horti-forestry plantation project, where a small plot of land (an acre) owned by a tribal family is brought under cultivation using a special model developed by BAIF. This model starts with planting 60 fruit trees in the plot, usually 20 mango saplings, 20 cashew, and 20 gooseberry, or depending on the bio-geography, some other native fruit tree variety. During a five-year growing period, where no fruits are ready for market, the rest of the plot is cultivated with fodder and timber trees on the boundary, and intermediate crops and flower trees in the spaces in between. The model thus allows the tribal family a subsistence farm produce for most of its own needs in the early years, while at the same time allowing them to stay near their village, and not migrating to other places in search of work. With training, and materials support from the NGO, water and soil conservation measures are implemented in the plot as well as surrounding hills. In five years, the family's fallow land is converted into income-generating assets. This model provides short-term as well as long-term gainful self-employment. Entirely organically grown fruits and other produce is then collectively processed in smaller village-level units, and further value-added and marketed through a larger federation of such units. The success of this formula (which includes many levels of techniques and farming/ restoration technologies) in sustaining tribal families as well as restoring denuded stretches of land in the state of Gujarat and Maharashtra, led to its large-scale implementation, with thousands of tribal families benefiting across numerous states of the country, not only through government-funded programs, but also through other organizations such as the Gates foundation. The model is a good case of SfP, as it lends to very-large-scale implementations, while at the same time remaining a flexible formula that can be adapted to the local variation of bio-geography, thus taking into account and working in tune with the larger socio-ecological patterns it is a part of, and acting so as to nurture and let it flourish (BAIF, 2018).

These three projects illustrate the possibility of SfP at larger scale, embedding the notion of flourishing as a design principle. However, they also show that it is pertinent to question the assumptions and implications of large-scale interventions. For instance, projects such as BAIF's Wadi project show how interventions can be contextual, decentralised, and yet, implemented within large geographical areas. 'Scaling-up' as conventionally understood may not thus be applicable to SfP-driven interventions. The essential design principle is harmony with the larger eco-social patterns. SfP requires that technological interventions, instead of focusing narrowly on maximizing any single outcomes of interest, finds a balance such that the larger patterns of society and ecology flourish / thrive, rather than get destroyed.

These three examples indicate a possible progression, from the current efficiency-driven design towards SfP. In this view, the current approaches of 'Green tech', systems engineering, or industrial ecology, can be considered as initial steps towards sustainability. SfP indicates where they fall short, and the direction in which these need to evolve.

Fig 5: A possible SfP trajectory, transitioning from the 'more for less' narrative (efficiency driven designs) to the idea of 'flourishing', as advocated by the SfP approach. The diagram indicates that SfP is not necessarily antagonistic towards efficiency, but seeks to promote wider aims. Other recent approaches cover some of the aspects that SfP supports, but do not explicitly promote flourishing.

4. Reshaping the building instinct

A new type of normativity, which is needed to engage with the ecosystem in a sustainable manner, *cannot* be instilled *only* through theoretical principles such as solving for pattern. This normativity can emerge strongly only from experiences, gained through engagement with practices such as farming, which embed a more interconnected and interactive approach to the human-nature relationship. These experiences contribute to a 'frame of mind' described by philosopher Michael Bonnet as follows, "To acknowledge this element of transcendence is to re-admit fluidity and mystery into the environment that can gift inspiration and lead us to new insights concerning the nature of sustainability and a frame of mind that it implies" (2013: 196). Technology envisioned within such a sustainable frame of mind is better equipped to solve for pattern.

The case studies suggest that embracing a SfP approach can help revive the web of eco-social relations that constitute these and other technological practices, and establish a culture of mutual reciprocity. The cases of 'making actions' – cultivation (UF) and construction (EP) – demonstrate an alternative to the merely efficiency-driven modern technology practices. These cases, and the perspectives they offer, indicate that it may be possible to overcome the short-sighted 'single parameter maximizing' approach to designing technology, by developing a more participative design approach that takes into account the socio-technical and ecological aspects of 'making'.

Given the short time frame available to move to sustainability, this way of thinking needs to be widely adopted fairly quickly. One way to speed up this process is through educational interventions that embed the SfP perspective, illustrating alternate ways of 'doing technology'. However, it is currently unclear how training and learning experiences that can nurture such a disposition towards engineering design could be developed. Case studies and role models have been identified as effective pedagogical tools for inductive learning in undergraduate education for professions (Conway, 2001; Goldie, 2000; Liddament, 1995). One of the ways to bring in the SfP practice and role models into undergraduate technology design curricula would be through theme-based case studies of technology building (Date and Chandrasekharan, 2018), such as that of EP and Arunachalam Muruganandam, who has designed machines that allow women's self help groups in rural areas to make and sell low cost sanitary napkins.

Engagements such as farming, emphasize the interdependence of natural systems, and the embeddedness of human society in ecology. Community-based activities such as urban farming (Dutta and Chandrasekharan, 2018) in schools could be another way to develop such engagement. Community farming provides a rich platform to highlight aspects of reciprocity in nature, through environmental stewardship, as well as understanding the deep relationships between various phenomena such as food, water, pest, predator, sunlight and soil. Such practices connect to social concerns of food security, seed sovereignty, usage of chemical inputs in industrial farming, food miles and other related issues.

The shift to SfP, and associated values, can possibly emerge quickly through such educational practices that embed understanding of, and respect for, the larger relationships 'making' has with ecology and society. SfP could thus reshape the very meaning and goals of technology, design, and building, beyond the limited contemporary definitions, and further help define and establish sustainability engineering in a new way at the operational level. The SfP design principle provides the hope that the building instinct could be reshaped quickly, to develop technology, in its broadest sense, that is designed differently, to enable the entire biosphere to flourish.

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