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Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building

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Abstract

Large-scale shifts in dominant technologies are the necessary components of a transition toward sustainability. Such shifts are difficult because, in addition to technological innovation, they require changes in the existing institutions, professional norms, belief systems and, in some cases, also lifestyles. In the languages of cognitive and policy sciences, higher order learning on a scale ranging from individuals to professional and business communities, to the society at large, is needed. Higher order learning is especially crucial in the types of innovations that depend mainly on *synthesis* of existing technologies and know-how to achieve radical reductions in energy and material consumption, as is the case with high performance buildings. One way to facilitate this type of learning is through experimentation with new technologies and services.

Drawing on our earlier concept of a Bounded Socio-Technical Experiment, in this paper we propose a four-level conceptual framework for mapping and monitoring the learning processes taking place in a BSTE, and apply it to an empirical case study of a zero-fossil-fuel residential building in Boston. Three major conclusions are that: learning took place both on the individual and team level, that individual learning primarily (but not exclusively) involved changes in problem definitions; and that team learning consisted of participant turnover until congruence in worldviews and interpretive frames was achieved. This case study also shows that we must think of innovating in building design as both a process and a product, and that both must be considered in the future efforts to replicate this building.

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This study highlights that technological innovation about technology as much as about people, their perceptions, and their interactions with each other and with the material world. Sustainability will not be reached by technology alone, but by deep learning by individuals, groups, professional societies and other institutions.

Keywords: Green buildings; Higher order learning; Small-scale experiment; Technological innovation; Socio-technical regime

1. Introduction

Over the past decade, environmentally oriented innovations in technology and services have emerged in all areas of the economy, driven by governmental policies, professional experts, market opportunities and social movements. The building construction sector, where interest in high performance buildings has been on the rise, is a primary example. This interest manifests itself in diverse ways, including: a growing number of so-called “green buildings”, mostly in the public and commercial sectors and on university campuses, and in the media attention they attract; emergence of well known professional standards, including LEED standards;[1] intensified marketing of technologies and materials for high performance construction;[2] and in the curricula of professional schools and good career prospects for architects with the knowledge of high performance design. Additionally, federal, state, and local governments are increasingly adopting policies to encourage high performance buildings, through tax incentives and subsidies, expedited permitting, or through adopting minimum requirements in public construction, while the US Department of Energy actively disseminates relevant information.[3]

In a different realm, the so-called “new urbanism” and “sustainable communities” movements magnify the above trends. Although often driven by broader considerations, such as quality of life, economic development, and equity, these movements converge with the current developments toward high performance buildings by promoting high quality construction that minimizes indoor drafts and air pollution, and other features that would collectively reduce energy intensity [1–3].

Changes are also occurring within other societal institutions concerned with community housing and development, not typically associated with environmental issues. For example, our recent survey of Massachusetts Community Development Corporations (CDC’s) has shown that in low income housing rehabilitation projects (mostly the traditional New England triple-deckers) a great majority of CDCs use design features that lead to considerable energy conservation, even though their financial sponsors or the state regulations do not require that. Notably, they couch these environmental innovations in terms of quality rather than environment [4]. In another local example, Alternatives for Community and Environment (ACE) seeks to reconcile the goals of environmentally just and sustainable development in the Roxbury section of Boston [5].

In the language of evolutionary economics, one might take the above trends as evidence of an ongoing transition toward a more sustainable socio-technical system of building design, construction, and maintenance. The concept of socio-technical system denotes a relatively stable configuration of

[1] LEED stands for Leadership in Energy Efficient Design, which is issued by the US Green Building Council.

[2] Examples of some of the active organizations include: National Association of Home Builders, National Green Builders Conference, Ecological Design institute, Sustainable Industry Council, National Council of Architectural Registration Board, US Green Building Council.

[3] www.energycodes.gov.

techniques and artifacts – as well as institutions, rules, practices and networks – that determine the 'normal' developments and use of technologies in a particular area of human needs [6,7]. Socio-technical systems fulfill socially valued functions that they, in turn, constitute. They also embody strongly held convictions and interests concerning particular technological practices and lifestyles, existing institutions, and the best ways in which these may be improved. Stability and resilience are central to socio-technical systems. That means that change is slow, involving both innovations in science and technology and changes in institutions, professional norms and practices, lifestyles, belief systems, and others.

Contrasting with the slowness of change in socio-technical systems is the pervasive belief that time is running out on finding ways to address the current global environmental problems, especially climate change. Many authors argue that the scale and complexity of these problems require rapid shifts in socio-technical systems of energy production, transportation, and construction. With regard to the commercial and residential construction, the stakes are high: in the US this sector consumes about one third of all energy [8].

Considering the resistance of socio-technical systems to change, the observed growing interest in "green buildings" does not guarantee that such a change is imminent. For example, the highly visible "green buildings" may become monuments to short-lived fashion or a prestige-seeking behavior by some well financed enterprises. In this scenario, the innovations might not diffuse into the mainstream professional and business practices, and the building practices in the residential sector – the largest consumer of energy for heating, cooling and powering buildings – might remain unchanged. Furthermore, the new professional standards, such as LEED, could possibly become no more than a checklist for developers seeking public recognition and government subsidies. Should that happen, the achievements of LEED standards in increasing performance of buildings would level off at a modest gain level, and the standard might become an impediment to, rather than a starting point for, more radical future innovations [9].

Indeed, so far the residential housing sector shows few signs of change toward high performance design and construction. There appears to be a disconnect between the technical know-how and the availability of materials on the one hand, and, on the other hand, their incorporation into the daily practices, routines and professional norms of builders and real estate developers. The consuming public (those who purchase the approximately 1.5 to 2 million new homes built in the US each year as well as others who make major renovations in their homes) has not placed high performance construction on their mental radar screen. This is not surprising, since in home purchase decisions the location, appearance, and the nature of the host community are the key factors, while the ownership period (in the US) is rarely long enough to justify additional upfront investments in green technologies. Understandably, the real estate agents, who see themselves as serving consumers' wants, do not feature energy or environment as selling points.

Society thus faces a dilemma: the dominant socio-technical system of building design and construction (as well as others, such as transportation) naturally resists the urgently needed *rapid* societal transition towards more sustainable ways to satisfy human needs and wants. Resolving this dilemma has kept analysts and policy makers active during the past years. All agree that one of the conditions for affecting rapid change is that the professions and other communities of practice linked to building design, construction, and maintenance fundamentally reconsider some of their norms, practices, and problem definitions. Stated differently, higher order learning on a scale ranging from individuals to professional and business communities, to the society at large is necessary. To that end, some authors make a case for government-driven changes in institutions and rules of behavior through major policy reforms. For example, the Netherlands adopted "Transition Management" as a cornerstone of its sustainability policy [10,11,6], based on the assumption that the traditional government policies and instruments are unfit to meet the requirements of sustainable development [12].

Other authors argue that, in addition to government policies and technological innovations, changes in lifestyles, values, institutions, and human behavior are necessary which would amount to a "Great Transition" towards sustainability [13]. The major dynamics for a Great Transition would be brought about by a global citizens' movement aimed at environmental and social sustainability and global and local equity. Major disasters and other unpleasant large-scale surprises could also trigger a collective self-reflection and lead to fundamental shifts in the perception of the adequacy of the prevalent socio-technical systems.

A more incremental way to facilitate learning toward socio-technical system change is through small-scale experiments aimed at developing, testing and introducing new technologies and services. We previously referred to this type of experimentation as Bounded Socio-Technical Experiments (BSTEs) [14]. Numerous authors refer to the importance of higher order learning in socio-technical experiments, and often note its absence [15,16]. Yet, with a few exceptions [14,15], little systematic study has been done on defining the learning processes in experiments, monitoring them, assessing their societal impacts, or examining the conditions under which learning occurs (or not), and by what mechanisms. Gaining a better understanding of the learning processes occurring within BSTEs and beyond them, through diffusion, is the subject of the research described in this paper.

In this paper we examine the learning processes in the design of a zero-green house-gas emission building in Boston, Massachusetts. The empirical observations are analyzed through the lens of a conceptual framework that we propose in Section 3. The framework draws on two types of sources: the theoretical and empirical literatures on learning by individuals, organizations, communities of practice and societal actors engaged in policy debates; and the work of Grin and Van de Graaf [17,18], who studied the learning process in a discourse over wind energy in Denmark. We conclude that higher order learning takes place on two levels: on the level of individual heterogeneous actors, and on the level of the project team. We map the learning processes, and offer some evidence for the likely diffusion of this learning into various communities of practice.

2. Conceptualizing higher order learning

Higher order learning is a radical change in interpreting observations (interpretive frames) and in solving problems and advancing objectives. The term "higher order" denotes what in organizational sciences has been dubbed "double loop" [19,20], or "generative" learning [21], and in policy sciences as "conceptual" learning [22]. It entails changes in the assumptions, norms and interpretive frames which govern the decision-making process and actions of individuals, communities and organizations, or which underlie a policy discourse. It occurs through reflection and self-evaluation. Higher order/double loop/generative/conceptual learning contrasts with lower order/single loop/adaptive/technical learning, respectively, in which problems are corrected or policies altered without changes in problem definition, interpretive frames or in norms and values.

Learning occurs through a feedback-stimulus mechanism, when the existing, well accepted, time-tested and trusted interpretive frames and competences receive feedback on their performance in solving a problem or advancing specific objectives. If, as a result of this feedback, it becomes apparent that the desired results are not forthcoming, these cognitive constructs become subject to reassessment and, if necessary, are replaced with new ones. A sense of urgency is an important facilitator of learning because it forces repeated trying (and failing) that is central to the learning process [23].

This broad concept of feedback-stimulus is consistent across a wide range of disciplinary writings about learning, from cognitive sciences to organizational sciences to policy sciences. Working within the context of cognitive sciences on how individual professionals learn through problem solving, Schön [23] showed in a seminal study that the process starts with an intuitive defining of the problem within the context of the interpretive frame typical for that professional group. The frame consists of a preferred problem definition and solutions, appreciative systems (value systems), and overarching theories. The initial framing provides empirical and normative guide for making sense of the situation and for launching the work. The actual problem solving consists of iterative "conversation" between a professional and the problem, through trial and error, which in turn leads to increasingly higher order reassessments: first the tools (lower order), then the problem definition, and finally the appreciative systems and overarching theories (higher order). It is via these increasingly higher order reassessments that learning occurs.

In the context of organizations, the stimuli necessary for higher order learning come from threats to organizational survival and success, failures, disasters and other surprises [19,20,24]. Senge [21] additionally writes about using mental model building and structured interactions, scenario building, role playing, visioning, system thinking and other group techniques that generate feedback on the accepted assumptions and behaviors, as the means to stimulate higher order learning in organizations (see also the review by Easterby-Smith [25]). Like Senge and others in the context of organizational learning, Berkhout emphasizes collective visioning and scenario building exercises as a vehicle for inducing learning on a scale of society [26].

Wenger [27,28] uses the "community of practice" as a unit of analysis in order to examine the mechanisms by which external stimuli induce learning in social organizations, both formal and informal. A community of practice may be a professional group, a social or political actions group, a formal organization, or other stable aggregate of individuals in a society. In Wenger's language, the feedback process that is central to learning takes place by way of interaction between the deep competency possessed by a community of practice and the experience it acquires by interacting with the outside world. It are these boundary processes that produce learning. Several factors can enhance learning at the boundaries: having something to interact about, such as a specific project or a problem to solve; ability to communicate in a common language; and the presence of individuals who serve as brokers of new ideas among different communities of practice.

In policy sciences, higher order learning is broadly understood as a collective change in prevalent views, norms, problem definition, and relationships among groups. Like organizational and cognitive sciences, this school of thought attributes learning to the presence of feedback loops between the existing belief system and interpretive frames, and new experiences. Authors such as Lee [29] and Van Eijndhoven et al. [30] emphasize the role of new knowledge (which must confront the accepted knowledge) in providing the feedback, while Sabatier [31], Keohane and Nye [32], Wildawski [33], Glasbergen [22], and Schön and Rein [34] emphasize interactions among groups with different belief systems and interpretive frames as the means for learning. Darby [35] and Gertler and Wolfe [36] show how interaction with technology and accumulation of tacit knowledge lead to learning. There is a widespread agreement that crises, a sense of urgency, and the availability of platforms for interaction are important facilitators of social learning [34,37]. Paquet [38] advocates social experimentation as an effective inducer of the processes leading to social learning.

Schön and Rein [34] see higher order learning, and subsequent re-framing of a problem, as the answer to solving intractable policy controversies. Such controversies usually arise as a result of an irreconcilable clash between different interpretive frames of the key actors. The clash can occur on several levels: concerning problem definition, the norms and values of the institutions to which the actors belong, and the broadly shared belief systems. Learning manifests itself in re-framing of the issues so as to accommodate different interpretive frames of the adversaries. Schön's recommendation on how to facilitate learning is to enhance interaction among competing actors and to maintain the sense of urgency.

Linstone [39] argues in favor of interaction of sharply different perspectives on a problem as the means for gaining deep insights. Using a three-archetype typology of how individuals in organizations approach difficult problems – technological, organizational/societal, and the personal/individual (TOP) – this author shows the benefits of integrating different actors' perspectives in enhancing the understanding of the problem and broadening the range of available solutions. Fischer [40] also uses the idea of multilevel discourse in public policy, especially in relation to complex socio-technical problems for which multistakeholder processes are needed, but which are also vulnerable to becoming intractable controversies. Fischer identifies four levels of increasingly higher order discourse: technical, on the level of specific tools, costs, benefits, and outcomes in policy implementation, all within a specific set of objectives; contextual, on the level of problem definition within a given interpretive frame; systemic, on the levels of setting goals and objectives in relation to societal needs; and ideological, on the level of fundamental beliefs about the social order.

In the present study we draw on Schön's and Fischer's multilevel interactions to map out the learning processes among the immediate participants in socio-technical experiments. The next section takes a closer look at a BSTE as a place for higher order learning.

3. Bounded socio-technical experiment as agents for social learning

Previously [14] we introduced the term bounded socio-technical experiment (BSTE) to denote a project exhibiting several characteristics. It is an attempt to introduce new technology or service on a scale bounded in space and time. The time dimension is measured in years (not decades or months), while the space dimension is defined either geographically (a community) or by a number of users (small). BSTE is a collective endeavor, carried out by a coalition of diverse participants, including business, government, technical experts, educational and research institutions, NGOs and others. There is a cognitive component to BSTE in that at least some of the participants, and definitively the analyst, explicitly recognize the effort to be an *experiment*, in which learning by doing, trying out new strategies and new technological solutions, and continuous course correction, are standard features.

A BSTE is driven by a long term and large-scale vision of advancing the society's sustainability agenda, though the vision needs not be equally shared by its participants. Its goal is to try out innovative approaches for solving larger societal problems of unsustainable technologies and services. This latter characteristic distinguishes a BSTE from, for example, solving a particular environmental problem in a community (such as alleviating pollution through traffic control) or from a strictly market-driven introduction of new technologies and services (for example, introduction of alternative electric-powered vehicles, such as Gismo, Sparrow and many others [41]. Small-scale environmental projects can be turned into BSTEs, where learning is enhanced and monitored (this would be a form of action research), by way of introducing a context, a vision, or environmentally driven new technological component.

A BSTE can provide an opportunity for testing the feasibility of a new technology or service before it is ready to enter the open market. It can develop and test new social arrangements among actors, and consider them as templates for other societal contexts. It is also a vehicle for drawing into the sustainability agenda actors who would otherwise not see a place for themselves in the types of projects in technological and system innovation that are often sponsored by powerful corporate, governmental, or NGO entities. A successful BSTE creates a functioning, socially-embedded new configuration of technology or service, which serves as a starting point for diffusion. An obvious indication that a BSTE is successful is when this new configuration first meets the initial expectations, and then is widely replicated and becomes a social, environmental and commercial success.

Another, less obvious (and harder to demonstrate empirically), measure of BSTE's success is the occurrence of higher order learning among its participants, even in the absence of wide replication. By this we mean one or more of the following occurrences: participants re-examine, and possibly change, their initial perspectives on the societal needs and wants the project seeks to meet as well as the approaches and solutions; participants examine and place the particular project in a broader context of pursuing a sustainable society; participants examine, and possibly change, their own perceived roles in the above problem definitions and solution; participants change views on the mutual relationships among each other relative to the specific project or the broader societal context, including mutual convergence of goals and problem definitions; participants change their preferences about the social order as well as beliefs about best strategies for achieving them. We demonstrate this kind of learning in the case study described in the next section.

A third indication of an experiment's success is a change in interpretive frames or problem definitions among two social groups: the future users of the new technology or service – the consumers – and the communities of practice represented by the participants in the experiment. Social theorists such as Storper [42], Luthans and Kreitner [43], Granovetter [44], Bandura [45] and Hamblin et al. [46] as well as theorists of technological diffusion, such as Rogers [47] emphasize both the cognitive and social processes involved. The cognitive component includes reflection, reassessment and re-framing, as summarized in the preceding section, while the social component entails transmission and diffusion of new ideas and knowledge: in this case from the experiment's participants to the communities of practice or from the users of the innovation to their social milieus.

In our earlier case analyses [14] we found, for example, that when ideas from a BSTE concerning a technological innovation in individual mobility were introduced to an unrelated project of solving traffic problems in a distant island vacation resort in the Netherlands, it led to re-conceptualization of the latter project and subsequently to very different alternative solutions than originally.

In regard to the users of the innovation, Rohracher and Ornetzeder [48] studied the impacts of living in green buildings on their occupants. The study showed that the presence of new energy-saving technologies impacted the occupants' views on the issues of energy and environment, and made them more open to accepting these innovations. At the same time, the impact occurred only among the owners of apartments, who participated in the planning, design and construction decisions, and not among tenants, who did not participate. The owners had more positive reactions to the changes in the daily routines imposed by the new technologies, incorporated them readily, and enjoyed them more than the tenants. These empirical observations are consistent with Darby's [35] view of learning as an experiential cumulative acquisition of tacit knowledge, and suggest that residential green buildings may be an important vehicle for higher order learning about energy conservation on a scale of society.

BSTEs, as defined earlier, have several characteristics that are conducive to higher order learning among their participants. The presence of heterogeneous actors who represent different organizations, communities of practice and institutional affiliations assures the presence of a range of interpretive frames and belief systems. Moreover, the very act of choosing to participate in the experiment suggests a willingness on the participants' part to interact with each other and with each other's interpretive frames. The vision of sustainability, which is the driving force for at least some participants, has the potential to provide a platform, an umbrella, for re-framing the clashing interpretive frames, should conflicts arise. By evolving around a specific tangible "thing" – the innovative product or service – the project provides focus and a shared language for the discourse.

Other design features can be purposefully brought into the experiment in order to facilitate learning. These include: creating a sense of urgency; making deliberate efforts to encourage self-reflection and reassessment by and among the participants; and facilitating the emergence of a common language. These features are not automatic in BSTEs. In fact, small-scale socio-technical experiments driven by the sustainability vision often lack the sense of urgency because of, for example, diminished financial risks through government subsidies.

The present study builds on the work of Grin and van de Graaf [17,18] to conceptualize learning processes in BSTEs. These authors applied Fischer's [40] and Schön's [23,34] frameworks of multilevel discourse to examine the learning processes occurring during constructive (or interactive) technology assessment. Their underlying assumption was that different professional communities (or communities of practice) can collaborate on a joint problem – despite partaking in different interpretive frames and problem definitions – as long as they share each other's problem definitions (shared, common or dominant problem definition) [49], or at least accept each other's problem definition as legitimate (congruence).

Grin and van de Graaf followed the differences in problem definition and the approaches to problem solving within three professional communities who participated in technology assessment for wind power in Denmark: technologists, policy makers and business. Using the concepts of iteration and discourse, they identified four levels of discourse within each professional group. They suggested further (but did not show in detail) how such multiple level interactions among different professional groups – each with a different frame of meaning, background theories, and higher order belief systems – would produce learning, starting with questioning of each others' problem definition and then shifting to higher order the discourse.

Three features make the Grin and van de Graaf's framework, originally derived from a study of technology assessment, useful for conceptualizing learning in BSTEs:

- Focus on using new technology to solve a particular social problem or to meet a social need;
- Participation by various professional groups who bring different perspectives to the process;
- Focus on problem solving and a multi-level discourse as pathways to learning.

The participants in BSTE bring with them diverse perspectives and competencies, which in turn affect the meaning they attach to the project at hand and the ways in which they seek to contribute to the project and its outcome. Factors such as professional training, self-interest, socialization through membership in political and professional groups as well as deeply held values and beliefs contribute to the variability. We group these differences into four levels (closely following Grin and Van de Graaf [17,18])

1. Problem solving according to pre-determined objectives;
2. Problem definition with regard to the particular technology–societal problem coupling;
3. Dominant interpretive frames;
4. Worldview.

Worldview denotes deeply held values with regard to the preferred social order, including such issues as justice, fairness, equality, freedom, private versus public good, and so on. Discourse at this level rarely occurs, is unlikely to produce changes, and is most dangerous for a collaborative project. This is because the views of this order are very stable within each participant group. Rather than closing gaps in deeply held beliefs, an open discourse in this domain may lead to a deadlock. Of course, differing worldviews do play a role in the overall process. They do so indirectly, by impacting the way individual participants interpret the meaning of the project *vis-à-vis* the private and public interests, or how they define a problem.

By interpretive frame we mean the approaches to making sense of observations and to identifying the most salient characteristics of a particular situation. It is strongly linked to institutional and professional affiliations of its holder, his/her self-interest, as well as the worldview. Well-established professional assumptions and norms of behavior can strong influence one's interpretive frame. Interpretive frame resists change, but can do so, especially in crisis situations.

Problem definition denotes specifying the task at hand or problem to be solved. Participants do so by examining the features of a particular situation through the lens of their respective interpretive frames and worldviews. Discourse on this level is a struggle or negotiation about problem definition and problem-solution couplings. For instance, professionals with a technical background are inclined to define the problem as technical whereas social scientists or public service agency employees would develop a more social problem definition. Learning on this level is adjusting problem definitions to reach consensus or, at least congruence.

Problem solving entails applying tools that the participant seems fit for addressing a previously defined problem, such as engineering analysis, cost–benefit analysis, risk analysis. The discourse at this level proceeds primarily among members of the same profession or community of practice. Learning at this level does not involve reflection on the objectives of the project, or questioning of the match between the social problem and the solution that the particular technology represents. This is first order learning.

The most intense interactions occur in BSTE on the second and third levels. This is where the differences in problem definition, motivations for engaging in the project, individual interests and organizational missions, and perspectives on the particular technology become most clearly exposed and are most likely to confront each other. The nature and the extent of the resulting higher order learning depend on the form that that confrontation takes, and the way it is managed by the BSTE participants. Generally, changes in problem definition are more likely than changes in interpretive frames.

It is also at these two levels of interaction that participants confront their own commitments to the process and its goals. Some may discover that they are not willing to engage with other participants in a way necessary to propel the experiment forward or are not open to self-reflection. They are likely to quit. New members might also join, either to fill the emerging vacancies or attracted to the project, the interactive process and possibility of learning. A BSTE is therefore a dynamic configuration not only from the perspective of changing ideas but also of changing membership.

4. Empirical case study of high performance building in South Boston

Data for this case study were collected through participatory observations at project meetings between July 2004 and March 2006, from personal interviews, and from documentary analysis.

4.1. Developer's vision and the challenge

The South Boston neighborhood, although geographically very close to the center of Boston, is strikingly separate from it. Framed on three sides by the Boston Harbor, and separated from the city center by a highway and a stretch of industrial buildings and warehouses, "Southie" has evolved into a self-contained blue-collar working community with its own traditions and culture [50]. Its residents are for the most part descendants of Irish immigrants who flooded this area at the turn of the twentieth century, and many still feel strong ties to their cultural ancestry. Ethnic and neighborhood pride have fueled the sense of separateness (over the past century, many leading politicians in Massachusetts came from South Boston).

But the neighborhood is changing. The rising real estate market, the growing interest among young professionals in city living, and the advantageous location – near downtown, the airport, and the commercial and cultural amenities of Boston – are squeezing out the area's long time residents. The gentrification process started in the 1980s – as conversions of industrial buildings into lofts – and has accelerated during the past years in the form of luxury condominiums for workers in the nearby financial district of Boston as well as suburbanites returning to urban living (so-called Bobo's: Bourgeois Bohemians [51]).

The project we describe is part of this trend. During the 1980s the developer in question converted a historic mid 1800s rum distillery building he owned into lofts, which he rents to artists. In 2003 he decided to build, next to the "Old Distillery," an approximately 80 unit and 150,000 square feet elegant residential building that would include apartments, open lofts, art studios and galleries. The developer is an atypical member of the real estate development community. With a doctorate in philosophy and with a personal history of activism in the Students for a Democratic Society movement during the 1970s, he divides his time between real estate development and social research and writing. He is committed to using his financial resources and creativity for the betterment of the society. Accordingly, the new building will minimize its use of fossil fuels and will price a number of its original lofts below market value, in effect having the wealthy residents subsidize the modest income residents (mostly artists).

The developer's ambition was to innovate in three areas: product (the building), process (designing and constructing the building) and end use (the life in the building).

With regard to the product, he sought to deploy as many cutting edge energy-reducing technologies as possible, including the architectural know-how on high performance design, and to rely on renewable energy (biofuel) for cogeneration of heat and power, so that the net consumption of fossil-based energy will be zero. The list of energy-efficient technologies initially included: solar heating panels integrated into the roof, heliostats to bring light into the interior, mobile louvers and reflecting shutters to modulate daylight and to provide insulation, photovoltaic cells, co-generation of heat and electricity, using waste vegetable oil from local restaurants as heating fuel, a greenhouse, storage of winter ice for summer cooling, insulation with heat exchange, air conduit systems for heating and cooling, and solar energy trapping by a glass south wall and porch. Taken individually, these technologies may not all be that new; it is their convergence into a single large scale residential project, and the process of incorporating them, that would be innovative.

Box 1
Technological issues

- insulation; compactness of building: minimizing energy losses on surface
- passive solar: glass porch on south; solar thermal in roof
- shutters and louvers
- bringing in daylight: heliostats and atriums; redesign of heliostats
- energy generation: cogeneration with biofuel: waste oil from restaurants.
- cooling: ground water and diurnal ice from overcapacity electricity at night
- transportation: car sharing; electric and plug-in hybrids, fueled by electricity from cogeneration
- vegetable gardens; tomatoes in atriums in winter; greenhouse

With regard to the process, the developer sought to arrive at the final design of the building by assembling a heterogeneous team – architects, urban planners, engineers, solar experts, energy consultants, grass roots promoters of biofuels, artists-tenants of the current building – and by setting in motion an interactive, vibrant, creative discourse. Underlying this approach was his belief in (1) the creative potential of interdisciplinary teamwork; and (2) the social benefit accruing from collaboration between business, professionals, artists, and grass roots activists. The developer also planned to employ local residents – those who loose the most as the result of gentrification – as contractors and subcontractors. In his vision, the benefits of doing so would extend beyond providing employment. He sought to engage these skilled workers in the exciting process of innovation in building design and construction, and thus to provide them with a new perspective on the role of their respective occupations in innovating for the environment.

With regard to the end use – the life in the building – the developer envisioned an organic vegetable garden, and a transportation link with the center of Boston that would encourage using alternatives to single occupancy vehicles. To that end, the developer planned to work with Boston's transportation authority to provide an efficient bus system for the residents of the building and its neighborhood, and to consider other options, such as car sharing services and electric bicycles and scooters. In this vision, the building would attract occupants of a certain class – "savvy, well-educated, well-off, 'elite cognoscenti', and critical of the status quo" – who would share with the developer and each other a belief that affluence needs not be equivalent with high energy consumption. The building and its occupants would ultimately become a model for innovation in technology, design, process, and lifestyles. All the participants, from the building designers to its future occupants, would hopefully acquire a fresh perspective on their own role and, through diffusion, pass that perspective on others within their professional and personal circles of influence.

The innovative process of designing the building presented a significant challenge because it in effect sought to change the traditional power relationships between a developer, an architect, and a team. In conventional building projects, the architect is in charge; working within the general parameters set by the developer, the architect makes the key choices with regard to the design, materials, technologies, consultants, and the constitution of the overall project team. This management model is acutely sensitive to efficient use of the experts' time, and is highly risk averse. The risk aversion is rooted in the large financial risks involved in residential construction, the very real threat of litigation in case the new technologies do not work as planned, and the prominent role of insurance industry in real estate development. The result is that project teams stay together from one project to another, and disincentives to trying new designs and technologies are strong.

In contrast, in this project the developer is in charge, and he assembled a team of experts who have not worked with each other before. Moreover, he asked these team members (including himself) to put aside their egos and some professional norms, and to work in an open ended, interactive mode, which he later called "friendly competitive", where a multitude of ideas would be put forward, jointly discussed, and possibly adopted. These ideas were scrutinized by outside experts as well as inside the group, with the developer as final arbiter. *In essence, they were being asked to view the contribution of their own expertise through the lens of the overall project, rather than seeing the project through the lens of their own expertise*. The personality of the developer was the greatest asset in favor of this unconventional process management scheme: he is a soft spoken individual with strong interpersonal skills, a superb networker and listener, is genuinely interested in technical analysis, and, despite keeping strong reins on the project, has a decisively non-authoritarian demeanor. His vision of the building was another asset, as long as it was shared by the team members. Nonetheless, as we discuss below, it was not easy to create a coherent project team that was able to comply with the developer's ideas for the process and the product.

4.2. The evolution of the process and emergence of the Core Team

By the end of the design stage the project Core Team consisted of six individuals who were intensely engaged in the collaborative process of designing the new building: Architect 3, Architect 4, Urban Planner, Energy Consultant 3, Staff Engineer, and Developer. We capitalize their names to denote their roles as actors in a drama of sorts, in which each was both a representative of a profession and an individual (with a name, personality, a value system). The Core Team emerged after one and a half year period of the design stage, and after a significant turnover.

Early on in the project, Developer engaged the Urban Planner for his knowledge of the South Boston neighborhood, extensive links to the architectural community in Boston, expertise in building models, knowledge of environmental regulations, and for his skills in navigating the complicated building permitting process in Boston. Planner was an accomplished engineer and architect in his own right. Developer also hired Architect 1. The initial drawings by Architect 1 were sleek but disappointing, showing little sensitivity to the energy and environmental aspects of the project. Architect 1's idea of a "green building" was to first design the building, and then bring technical specialists to add the "green" features, in particular photovoltaic. Since this was fundamentally at odds with Developer's goal of integrative design, zero fossil energy consumption, and affordability (which photovoltaics is not), this idea was rejected and he left the project.

About that time, Developer hired Energy Consultant 1 (a solar design specialist), and further a specialist for heliostats and louvers, and a local grass root activist specializing in promoting biofuels. The activist worked on an on-site biofuel-fired co-generation facility with the in-house Staff Engineer, who was responsible for technical maintenance of the existing Old Distillery. Originally Developer saw the project as a collaborative between established business and grass-roots activism. However, the activist did not value business culture, and after the permit for co-generation plant was secured, left the project, while the Staff Engineer continued in an advisory role to Developer.

Architect 2, with a high reputation in constructing high performance buildings in Boston, was attracted to the project because of the innovative nature of the proposed building. His ideas were indeed more promising than those of Architect 1. The major advancement was to settle on a bulky, energy conserving four- or five-story structure with a large L-shaped footprint. The concept of internal light shafts emerged at this point, to solve the problem of delivering light to the interior walls of the apartments. Heliostats (revolving mirrors on the roof) would reflect sunlight from the roof down through the light shafts and into the apartments. Four apartments on each floor would be served by each light shaft, and by a stairwell.

Both Architect 2 and Energy Consultant 1 were asked to engage with Developer and with other technical experts in interactive open-ended, free flowing brainstorming sessions. However, it soon became clear that Architect 2 was not willing to adapt to this unusual mode of producing a building design, to the loss of control over the project, and to the demands on his time that this process made. Energy Consultant 1 also resisted the process, especially the loss of control and the fact that the Developer asked him to consider their firm's specialty, photovoltaic panels, as only one of several technological options.

Box 2
Design issues

- "green minimalist" gave way to "distinctive but conventional" design
- seize and layout of atriums
- orientation of apartments (inward or outward looking)

In January 2005 the project was in disarray. The original idea of a "vibrant multidisciplinary team" to jointly solve the problems, was not working out. According to Developer, the participants became more entrenched, and "nobody was interested in learning anything from anybody". Both Architect 2 and Energy Consultant 1 left the project. However, Urban Planner, after initial skepticism, bought into the interactive team process and became its strong supporter. And soon new actors entered the project.

Architect 3, who replaced number 2, is a well-respected elderly retired gentleman whose experience goes back to Bauhaus and Gropius. His philosophy is that architecture is the means of improving human condition and preserving human dignity, and thus a building must be designed so that it satisfies some particular human needs. He sees a building as an esthetic solution to a particular problem. Architect 3 embraced the interactive interdisciplinary team effort. Although it was mutually understood that Architect 3 would not take the responsibility for the entire project, he made some key contributions to it: he changed the spatial orientation for the building, and replaced the light shafts with much larger atriums.

The atriums are designed to bring daylight in all levels deep into the building. They also fundamentally redefined the aesthetics of the building by opening the possibility of growing bamboo plants from the ground level to the roof, which would provide a view of sorts to the interior windows, by introducing an idea of window boxes with flowers (or tomato plants), and by providing more privacy than the narrow light shafts. The Developer seized the opportunity by introducing the idea of semi-tropical gardens in these atriums, with flowers and birds year round. However, they raised a number of issues concerning the layout of the apartments and the issue of how much ‘leakage’ of heat and cooled air would happen through these atriums. It also added extra costs, which became an issue later in the design stage.

One could dramatically impact the relationship among the inhabitants of the building and between them and the community outside, depending on where the living room windows would be placed, the orientation of the garage and the main entrance, and whether the apartments sharing the same elevators were also sharing each other’s (fairly intimate) view across the atriums. At one extreme, the interaction among the occupants would be enhanced, leading to the emergence of a strong sense of a community among them, but in that scenario the building would turn a blind face to the street. At the other extreme, the opposite would be true. The views of team members differed, with the Urban Planner favoring the community engagement, and Architect 3 focusing on creating a community among the building occupants. While the final answer was a compromise on both counts, the debate led to a lot of reflection. Furthermore, it gave rise to a new idea about the future life in the building: that the ground level space of the building would contain, in addition to art galleries and retail, also commercial rental spaces to attract the progressive innovative businesses specializing in building design and technology. In this vision, the building would become a hub for the Boston area innovators.

Architect 4 joined the project a year into the process, and became its chief architect, with Architect 3 remaining on the team. Architect 4 has a long-standing interest in high performance architecture, knows well some of its more famous examples, such as the Beddington Zero-energy development in the UK, and has strong ties with the engineering community in Boston. He is cautious about the current “green” movement within the profession, concerned that it could reduce the consideration of building’s performance to numerical scoring (as in the LEED certification), and thus rob the design of both process and content, and, ultimately, of creativity. Architect 4, after a long and successful professional practice within the established institutions in the UK, Africa and the US, opened his own solo practice in Boston a few years ago. He was seeking more challenges, less constraints, and opportunities to apply architecture toward solving social problems. The South Boston project was a perfect match.

Architect 4 found an instant understanding with Developer about his values, personal mission and the view of this project. The interactive team process looked to him both intriguing and exciting. Having two architects on the team seemed more like a source of creativity than a threat.

The last two persons to join the team (during the second year) were Energy Consultant 3 and the project manager. Developer brought in Energy Consultant 3 on the urging of the then Core Team members, who all agreed that the team needed someone to integrate the various technological and design ideas into a coherent whole. Energy Consultant 3 followed on the footsteps of departed Energy Consultant 1, and, for a brief and unremarkable time, of Energy Consultant 2.

Energy Consultant 3 is also a member of a non-profit organization in Boston that is dedicated to transforming the residential building industry and thus furthering the goals of sustainability. The organization concerns itself with both the environment and social and economic justice; it accounts in its designs for energy efficiency, environmental footprint, affordability, and quality of residential construction. Energy Consultant 3 shared with Developer and Architect 4 the key aspects of their vision, such as zero use of fossil fuels, providing affordable housing, and challenging the dominant practices in the design and construction of residential housing. In the past, he has been a strong supporter of an interactive process such as the one applied in this project.

The Core Team emergent in the second year thus consisted of Developer, Architect 3, Architect 4, Energy Consultant 3, Urban Planner, and Staff Engineer, with additional several experts and advisors for specific issues, as needed. Core Team continued to meet once or twice a month for long discussions, with follow-up and more focused work in smaller configurations. Gradually, the meetings' style changed from democratic and egalitarian to managed interaction under a clear leadership by Developer and Architect 4. Notably, in that process, Developer became highly conversant in all the technologies and their functions, as well as their role in the overall life of the future building.

The financial viability of the project became a central issue during the second year. Uncertainty in the real estate market and the difficulty in estimating the final costs of the entire project, led to various strategies. One was to build the new development in two phases: phase 1 would incorporate some new technologies and provide possibilities of learning along the way, and phase 2 in which all cutting-edge technologies and the atriums would be realized. This led to discussions about the permitting strategy: should permits be acquired for the two phases separately or jointly? Another idea was to rent, rather than sell, the units for the first few years, thus minimizing the chances of litigation by owners in case glitches in the technologies would occur.

At that time, Core Team also produced a value statement for the project. The Statement of Values is an interesting document in that it represents Core Team's *collective* vision for the project. It was intended as a team-building instrument, and as a platform for communicating with all the stakeholders, both internal and external to the project (including the permit issuing agencies, politicians, marketing agents, and so on). It would also be a guide for critical decision-making and conflict resolution among all the firms and individuals who would construct the building. The Statement also embodied the collective learning process that took place over the year and a half period of time during which the Core Team emerged and found its identity as a creative and effective group who set out to create an innovative building with a social mission.

4.3. Analysis of learning processes

Figs. 1 and 2 show the model of the building and its environs, including the existing "Old Distillery". The innovative nature of this building lies in the *synthesis* of existing technologies, not in the technological inventions per se. The greatest energy savings accrue from the bulky compact shape and large size. Energy Consultant 3 told us about his surprise in finding that the aspect ratio (the ratio between surface and content) generated by a computer model was that low. He did not think about it when first approaching the project.

The atriums are an old architectural concept, though certainly their function in this building has a new meaning, especially in combination with the heliostats. Neither is co-generation new, although the combination of co-generation with bio-fuels and with residential construction is. Similarly, the greenhouse and the elevated courtyard contribute to community building and the aesthetics, but are not radically new features.

The implementation process and the project's goal are innovative. A team-centered interactive process, driven by a value statement has been applied elsewhere (as Energy Consultant 3 noted in the interview), but this project team was larger, and the duration of the deliberations (a year-and-a-half) was longer by far than the usual practice. The goal of the project was to integrate cutting-edge environmental technologies and design know-how in a synthetic and innovative way in a residential building that would both be a commercial success and perform a social mission. The social mission consisted of (i) reducing consumption of fossil fuel; (ii) challenging the conventional practices and norms within the architectural and construction professions and in the emerging specialty of so-called "green architecture"; (iii) creating

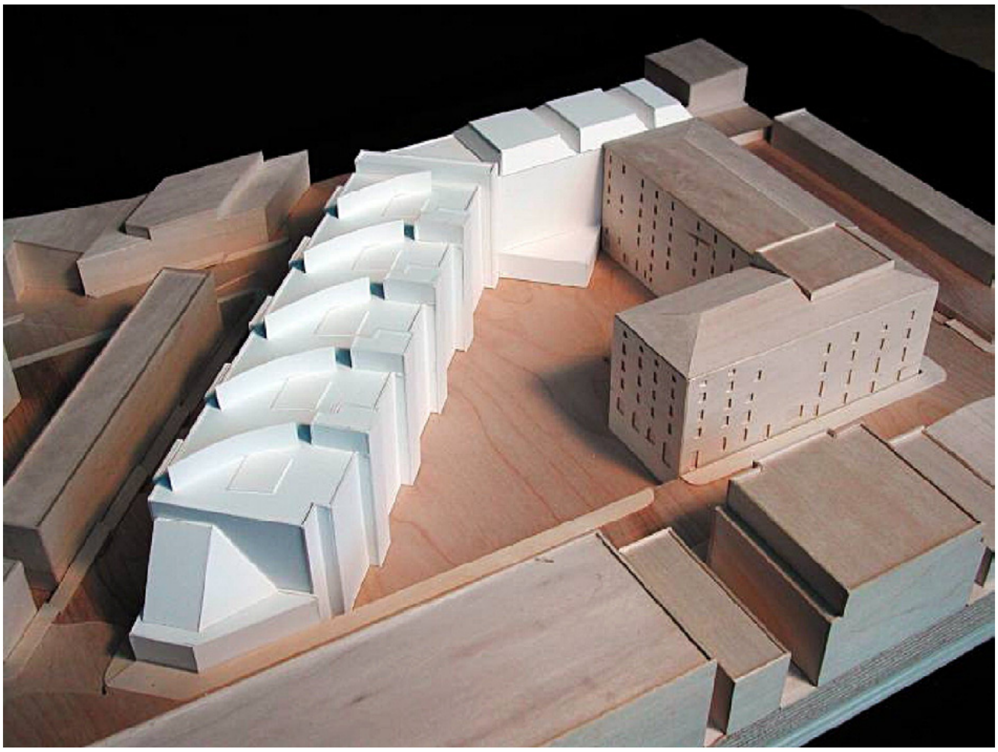

Fig. 1. A rendering of the existing 'Old Distillery' building (dark) and the projected new residential building (light).

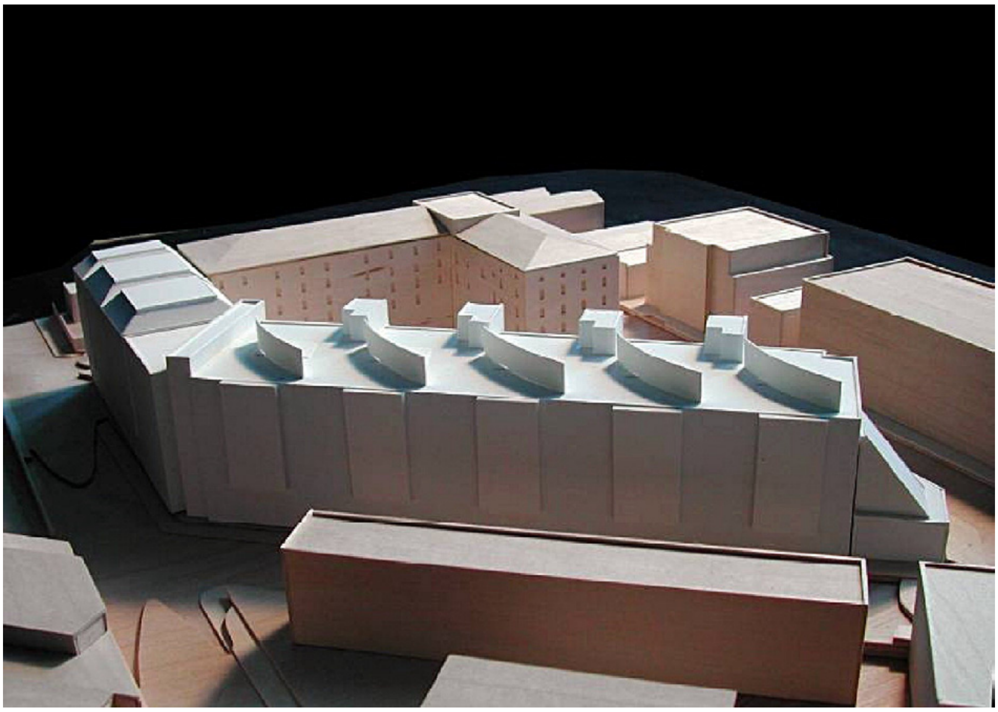

Fig. 2. The complex as seen from the NW: On top of the roofs the heliostats are visible.

a replicable model of a zero-energy building, and of a collaborative team-based process of designing it, which would include different professional and occupational communities of practice; (iv) creating a replicable model of lifestyles in which wealth is not synonymous with a large environmental footprint. In short, this project fits the definition of a Bounded Socio-Technical Experiment we gave earlier, and the process it followed – interactive, heterogeneous, focused on a specific goal, and with a sense of urgency created by high financial stakes – was highly conducive for higher order learning.

Building an effective team capable of pursuing the technical, economic and social objectives of this project took some time and a substantial turnover among the participants. In essence, the final chief architect (#4) and Energy Consultant 3 stayed with the project because they fundamentally shared with Developer and each other its objectives and the larger mission. Along the way they learned, and so did other members of Core Team. Below, we analyze the learning processes that took place by the four most active members of Core Team in the course of this experiment, using the four-level conceptual scheme that was introduced earlier.

Table 1 summarizes the views and beliefs of Architect 4, Urban Planner, Energy Consultant 3, and Developer at the start of their participation in the experiment. The first thing to note about Table 1 is that three of the Core Team members have very similar worldviews (level 4). They believe in the power of technology, creativity and collaboration between business and other societal actors in producing social good, they see the need for pursuing social justice through urban development projects, and are committed to the goal of sustainability.

Their primary interpretive frameworks (level 3) also show strong similarities. The three believe that prevailing professional practices in building design and construction are in need of major innovation, believe that existing technologies, if integrated cleverly, can produce a zero-energy building that fits into the neighborhood, and see a collaborative team work as an effective method of achieving these. Within these similarities, Developer and Architect 4 emphasize the life in the neighborhood and among the building occupants to a greater extent than Energy Consultant 3.

Urban Planner's interpretive framework shows similarities with the others, in that he, too, believes in the power of current technologies in reducing environmental footprint, and in accounting for the needs of the community in urban development projects. However, his primary emphasis was on satisfying the needs of the neighborhood and of the local institutions, not to pursue sustainability. As noted earlier, Urban Planner had initial misgivings about the process adopted by Developer, but over time became its strong supporter.

The above similarities put the fact of the team turnover in a new light. The turnover was a process of *learning on a scale of the team*. The team members came and went until a team with a definite identity emerged. This identity derived from the collective view of the preferred social order and a collective set of interpretive frameworks that could represent all the individual frameworks. The Value Statement signaled the emergence of this team.

Table 1 shows that differences in interpretive frameworks among the four individuals, though not great, led nonetheless to notable differences in problem definitions. Our analysis also shows that most of the individual learning took place on the level of *problem definition*. In the beginning of the project, Developer focused on maximizing the number and variety of ideas, and to somehow turn them into a coherent building design through a democratic, egalitarian, interactive and inclusive process. This process, rooted in Developer's views on authority and democratic participation, turned out to be too open-ended to produce progress, even for those team members who stayed with the team, and was later replaced with a disciplined core group effort under the leadership of Architect 4. In an interview,

Table 1
Four-level learning scheme for the key members of Core Team

	Developer	Urban planner	Architect 4	Energy Analyst 3
1. Problem solving	Assemble, motivate, and manage heterogeneous team. Synthesize technologies and design while balancing competing objectives.	Move the design process along towards successful approval and permitting.	Move the design process along while allowing maximum creativity.	Understand the conceptions of other team members. Analyze and optimize energy flows of many alternative designs.
2. Problem definition	How to generate a multitude of ideas through interactive brain storming within a shared vision, and through an inclusive egalitarian group process. How to integrate as many innovative technologies as possible into a coherent design.	How to get to know the community and institutions; then meet their requirements within Developer's parameters.	How to integrate ideas emerging through interactive process into a coherent and cost effective design, guided by a shared vision.	How to optimize the energy management of a building while integrating multitude of other ideas and meeting competing objectives.
3. Dominant interpretive frame	Existing technologies can produce a radically different building: energy efficient, affordable, beauti ful, enhancing neighborhood and lifestyles. Current professional practices impede innovation. Project-related egalitarian and inclusive collaboration of professions and communities of practice leads to innovation.	Urban development should be integrated with community needs. The community and local institutions can impede real estate development projects; advance business by satisfying their needs.	Existing technologies can produce radically different building: energy efficient, affordable, beautiful, enhancing neighborhood and lifestyles. Distinction between design and green design is false. Current professional practices impede innovation.	Energy efficiency, high quality, and affordability are key features of sustainable design. Current professional practices impede innovation. System thinking and integration are is key to sustainable design.
4. Worldview	Business, professions, technology and civil society can collaboratively produce change towards environmental sustainability and social equity. Democratic participation can take the function of strong authority.		Business, professions and technology can collaboratively produce change towards environmental sustainability and social equity.	Business, professions and technology can collaboratively produce change towards environmental sustainability and social equity.

Developer mused that "nothing I have learned ever presented authority and discipline as anything more than an atavistic issue of a bygone era... [I learned] that unless there are secure boundaries, firm rules and the guarantee of sanctions, dialogues and free participation are impossible."

Developer also discovered that designing a building with a radically higher energy performance is an integrative process all the way through. At the outset, he rejected what he perceived as an unfortunate practice of designing a building and then adding to it "ecological features", such as photovoltaics and others. But inadvertently, he landed in another unworkable extreme mindset: assembling a list of innovative technologies and seeking ways to deploy them. The process of designing the South Boston building has taught him that technological features and the design must co-evolve.

Architect 4's problem definition accounted at the outset for the co-evolutionary approach to the design. He did view the function of environment-sensitive technologies as solving particular design and performance objectives, not just making the project "green". This problem definition flowed from Architect's 4 rejection of the current trend toward identifying green architecture as a separate professional specialty, and his broader view of his profession (as noted in the interpretive framework). What Architect 4 learned during the project was a deeper appreciation of the creative power of collaborative, interactive, interdisciplinary team, given sufficient time. A conventional architectural design competition would not have created this level of open ended interdisciplinary creative interaction.

Architect 4 also came to see new opportunities for the architecture profession. In an interview, he described the new pressures on the profession in the USA, as builders and building suppliers increasingly encroach on what was once strictly the architect's territory: generating technical drawings, creating design ideas, and thinking of the aesthetics. In his future vision, architects will let go of the old idea of being the only source of the aesthetic and creative part of the design, and of being solely in charge of the entire project. Instead, they will engage in a collaborative interactive process with other relevant professionals, and make powerful use of their powers of lateral thinking and synthesis. In short, the *interpretive frame* of Architect 4 has shifted. Architect 4 also came to think about this project through Developer's lens: as a replicable model of a different building, different process of designing a building, and a different lifestyle among its occupants. By doing so, Architect 4 moved closer to Developer's social mission.

Urban Planner's problem definition changed. A veteran in the Boston area real estate development, he saw initially the design process as strongly guided the requirements of the neighborhood and local institutions, while also satisfying the developer's goals and the architect's ideas. By the end of the design process Urban Planner began to see all these steps and (possibly competing) objectives in a more integrated way: a sustainable building design takes place through an interactive process that accounts for all perspectives, and *is* therefore attractive to the neighborhood and institutions. The process of obtaining building permit consists of articulating the project's vision and its product: the design.

Energy Consultant 3 viewed this project as a technical challenge, a symbol and an instrument for advancing the cause of technological change toward sustainability. Through it, he sought to demonstrate that reducing energy consumption by 80% can be done with current mainstream technologies and in the very difficult Massachusetts climate, which ranges from extreme winter cold and dryness to extreme summer heat and humidity ("if it is done, then it is possible", he mused). He sought to create a replicable model; to teach the construction professionals, through empirical experience and subsequent diffusion of knowledge, about high performance buildings; He further aimed at raising the departure point for further incremental innovations in high performance and environmentally sustainable construction.

His specific initial contribution to the project was to balance the Developer's enthusiasm for incorporating as many innovative technologies as possible with the considerations of costs, effectiveness, and priority setting. Since the (bulky) shape of the building reduced the heating requirements substantially, the considerations of passive solar – rather standard in high performance design – became much less. Instead, the analysis focused on efficient cooling system (alternatives included: groundwater circulation, aquifer storage, annual ice storage, and diurnal ice storage), cost containment, equipment efficiency, fuel availability for the co-generation plant, and maximizing the residents' access to the attractive atriums. Other issues included the design of underground parking and the greenhouse and the designs of the roof heliostats.

The problem definition of Energy Consultant 3, focused as it was primarily on the energy aspects of the building, followed from his interpretive framework. It also accounted for the team process, which he entered when it was already well established. Notably, Energy Consultant 3 did not become the main force in integrating all the innovative technologies. This role fell upon Developer, with the help of many advisors. Rather, Energy Consultant-3's focus remained on the energy flows in the building.

5. Social learning through BSTEs toward socio-technical transitions

The case study in South Boston shows that bounded socio-technical experiments can indeed induce higher order learning among its participants, mostly at the level of problem definitions, but also, to a smaller extent, in interpretive frames. The key factors contributing to the learning include: the presence of a clear focus and boundaries for the project (to create a building); intense and sustained interactions of several professionals with a commitment to the process and the goals of the project; the sense of urgency (rooted in the time and financial pressures); agreement among the participants about the vision for the project and its social mission, and about the process; agreement among them about the core social values, and overlap among the participants' interpretive frameworks. These factors constituted a bedrock on which the project participants could interact, solve problems, reflect on their individual interpretive frameworks, and make changes in individual problem definitions. The availability of adequate time and funding also greatly helped. We also found that the participants who did not experience all of the above learning factors mostly left the project.

This case study also identifies two units of analysis for studying the interactive learning processes: the individual and the team. On the team level, the learning involved a gradual formation of a team that has the capability to carry out the socio-technical experiment envisioned by the project champion. As it turned out, the experiment required that its participants have a wide agreement on the fundamental values and interpretive frameworks. The team composition thus kept changing until this condition was satisfied. This observation is analogous to Schön and Rein's [34] observation that intractable policy controversies arise from clashes between the contending parties' core worldviews and interpretive frameworks. To resolve such controversies, these authors recommend re-framing the problem in a way that eliminates the clash.

In our case, deep conflicts were eliminated when the initial participants were replaced with others whose values and interpretive frameworks allowed congruence. The newly emerging core team resolved the remaining issues by multiple interactions and discussions, re-framing and reformulating problems, collectively seeking solutions, each from an individual perspective and expertise. The Value Statement was the embodiment of these fundamental agreements. The members of Core Team also agreed that the Value Statement, introduced early in the process, could be a powerful tool for selecting a design team and a construction team.

From the practical perspective, this case study shows that we must think of innovating in building design as both a process and a product. That means that when we want to replicate this building, we must ask two questions: "what is it like and what features does it have?" and "how was it developed and by whom"? This is a fundamental lesson about socio-technical innovation through small-scale experiments.

Will the higher order learning that took place in this BSTE diffuse beyond its boundaries? While the scope of our research cannot provide an empirically-based unequivocal answer, several factors suggest that it will. First, the Core Team members have been energized by three ideas: that the building will serve as a model to emulate; that the design and construction of an socio-technological innovation can and should be driven by a social mission and an explicit statement of values; and that the technology, the know-how, and the professional capacity exist to propel the existing socio-technical system of residential building construction towards a major shift. By own admissions, they intent to carry these ideas "back" to their respective communities of practice. Indeed, Architect 4 is, at the time of this writing, about to assume the presidency of the regional society of architects, and has rich plans to influence his profession accordingly through that post.

Second, market forces in the design and construction industry facilitate the diffusion. Both Architect 4 and Energy Consultant 3 noted that individuals and firms who have in their portfolios "green buildings" use them as a competitive advantage in typical bidding competitions. This project, if brought to completion, will raise the bar on what counts as an innovative green building, thus giving the participants an additional competitive advantage.

Third, an important new idea emerged about the future life of the building: to attract innovators in environmental technologies and building design to the commercial rental spaces of the building. The first such business, the team member specializing in heliostats, is now renting a space in the existing Old Distillery building, and will eventually move to the new building. Such a physical convergence of innovators will have a synergistic effect on the innovation process on the small and large scales alike. The potential for social change form creating such a critical mass, including the building occupants and resident artists, is hard to overemphasize.

In the next phase of the project, construction and use, new actors will interact with the project, such as construction companies, local authorities (who are keeping a keen eye on the project), citizens' groups, legislators, and building occupants. Owing to the different perspective of these actors, along the line of Lindstone's typology [39] and our own conceptual framework, controversies and insights are likely to arise then with regard to the significance and uses of the building. Learning will be stimulated through that process.

6. Conclusions

This case study shows that the four-level conceptual framework we developed is useful for studying the learning processes in small scale experiments aiming at a socio-technical regime shift. The term "Bounded Socio-Technical Experiment" we give to *some* such experiments emphasizes the importance of higher order learning through interactive processes, of the presence of a guiding vision, and of the congruent worldviews among the participants. Considering the profound importance of small scale experiments in producing major shifts in socio-technical regimes, a detailed analysis of learning processes is important for better theoretical and practical understanding of such shifts, and for developing the right conditions to facilitate them. Higher order learning is especially crucial in the types of innovations that depend mainly on *synthesis of existing technologies and know-how* to achieve radical reductions in energy and material consumption, as is the case with high performance buildings.

Studying in minute details the BSTE in designing a zero-fossil-fuel residential building uncovered what was learned, by whom, at what level in the four-level scheme, and on what scale. Three major conclusions are that: learning took place both on the individual and team level, that it primarily (but not exclusively) involved changes in problem definitions, and that in considering future replication of this project, the process will be just as important as the product.

While we cannot draw generic conclusions from one case study, we hope that this framework will inspire and enable other researchers to perform similar studies in other areas like transportation and agriculture. Comparison of perceived conditions for successful BSTEs and learning would then become possible. Conditions for diffusion of learning into wider society, and thus ultimately for large-scale societal transitions towards sustainability, are yet to be explored further.

Finally, this study highlights that technological innovation is as much about technology as about people, their perceptions, and their interactions with each other and with the material world. Sustainability will not be reached by technology alone, but by deep learning by individuals, groups, professional societies and other institutions.

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