archê-technê:

Notes on the architectural and philosophical scaffolding of new technology concepts for robotic materials, and their implications for practice.

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Introduction.

My interest in self-reconfigurable robotics is from a design perspective. On the practical level, I'm interested in the possibility of robotic materials. There are two reasons: First, they suggest possible alternatives to current interaction practice, through its questioning of traditional approaches to robotics. Second, it offers the promise of a new, generalized spatial media. On a more abstract level, simply thinking speculatively about projected technologies is fraught with academic practice issues. As you can see, the act of considering robotic materials opens a wide range of questions about the nature of design practice, well beyond the how-do-we-do-it of technical inquiry.

But first: a note concerning style and structure. This paper is preliminary thinking. I provide this as something of interest, but not as a finished work. As a result, there are no citations or references other than what came out in the flow of getting ideas down: if you want to know where the ideas are from, I'm happy to provide the references. I'll endeavor to add the citations etc. as soon as I return to this work for thesis writing reasons.

As a result, I'm not presenting finished work, but rather thoughts in progress on this topic. Some thoughts have advanced a fair way. Others are in turmoil. Still others are only just popping up, but their importance seems immediate.

I'm also following a structure that enables me to jump into different areas of knowledge. I'll be starting by outlining a very clear separation of interaction design from computer science. Rather than hold scientific approaches as primary, I assert they are part of a designerly approach. I do this for two reasons, so that I can ground you in some key concerns of mine, and to later culturally justify the role speculation plays in my interaction design practice. Next I will talk through some issues in robotics that are relevant to my work, so that I can more clearly outline my speculative work in thinking through robotic interaction. Following this outline, I'll show you the threads of architectural and philosophical thought in my practice. Then, picking up that designerly thread from earlier, I will finally talk through how I see speculation as part of a more encompassing architectural practice, one that goes beyond building design into technology stewardship.

It's all a bit interlinked. But then, if it were hierarchical bullet points and clear structure, I'd bore myself senseless, do the work injustices and rob you of the opportunities you'll make for yourselves while listening and thinking.

One view of the state of play between interaction design and HCI.

Let's start with the grounds of designerly thinking in interaction, and how this relates to my practice in expanding tangible interaction.

Disciplinary boundaries are by their nature permeable, shifting with trends and discoveries. Yet it is clear enough that we can distinguish them from each other, despite their admixture in the general structure of human knowledge. This is our human genius for pattern recognition at work. Such pattern recognition, when applied, allows us to construct lineages of knowledge, tracing out family trees of academic practice.

Interaction design's genesis is to be found (amongst other places) in the discipline known as HCI, or Human-Computer Interaction – a Computer Science sub-discipline, with an imported human factors pedigree and a belief in the primacy of both scientific disciplinary identity and scientific practice, which nonetheless has all the hallmarks of a strong engineering design culture.

The story of interaction design is by necessity a series of narratives, each emphasizing certain aspects of the discipline. The stories I am going to relate in this first part of my talk serve an ulterior motive; my aim is to situate you, the listener, next to me as I work through this particular problem. This is the disciplinary back-story that fills in my approach, and provides the context within which I have begun to work. It's not a back story shared by all my colleagues; rather, it's a personal attempt to make sense of threads I perceive in the admixture of my own discipline, and give you some idea of where I'm coming from.

Given I will be talking about massively parallel microrobotics later on, the question might be asked – why do we need to investigate narratives of interaction first? The answer is that several themes will come to light which can be considered in terms of robotics, and which will guide and ground my further exploration of robotics. The first theme is the shift from a traditional science understanding to a design understanding, and what this might mean for practice models; the second, a concurrent rise in the use of interdisciplinary activity in design; and the third, a shift in our very perceptions of what the technical structures generated by the discipline *are for*, so to speak.

The narratives of interaction I will foreground here tell of how a discipline has moved forwards in questioning its problems. For interaction design, throwing off the empirical-rationalist shell of HCI's mythical identity as a science, and realizing that as a Design discipline it is separate (yet related) to Computer Science, has enabled a wider ranging inquiry to occur, one which engages academic disciplines originally outside the remit of Computer Science, such as poetry and critical theory, as well as anthropology and Continental philosophy – and most importantly, one which understands its role as a *design* discipline without forgetting the treasures of its history. This in turn has been both prompting and prompted by a reconsideration of the role of computing – a reconsideration ironically brought about by the success of HCI as a clandestine design discipline.

Let's start with the gradual shift away from the primacy of science within interaction design. A little history is in order. The overtly political distinction of the HCI field as scientific is tangled up in the cultural construction of a claim distinguishing computing from the traditional engineering disciplines. I would note that ENIAC, the first programmable digital computer, was built in the Moore school of engineering at the University of Pennsylvania, by a team of engineers who in no way considered themselves computer scientists. This was par for the course in the first 20 years of computing practice. Coining a term such as "computer science" would wait for efforts, such as those of Fein from the late 1950's, to establish distinct Computer Science programmes in American universities. The political aim here was to distinctly narrate a sufficient difference to computing, such that practitioners could justify the required autonomy from engineering and prestige that their practice needed to thrive. As such, computing in general was marked with the identity of science, and practice since the 1960's has been informed by this political action. Yet the need to interact with computer systems pre-dated such niceties; interaction design (even in the form of punch cards) has been with us since near the beginning.

One of the ways the nascent HCI, as part of this structure, attempted to delineate its own scientific identity was through appropriation of various models from human factors research. The idea here is pretty much – if we use these models, we can test rigorously in a fashion that permits objective appraisal, thus justifying our membership of the Computer Science faculty. Fitt's law is the classic example – the well-known and ongoing application of a human factors theorem, which measures hand-eye movement and response times. The benefit of this metric was that it allowed for the ongoing testing of human interaction based on the quantitatively measurable most efficient use of action, and provided a means by which user-input devices could be tested and compared.

On the back of this success, a range of metrics were implemented, drawing not only from human factors but in the case of GOMS from psychology. Guidelines, the most well known being Shneiderman's Eight Golden Rules, also attempted to codify laws of interaction.

Yet no simple application of metrics is sufficient to transform an engineer into a scientist, and no guideline is a law of physics. Otherwise, designers applying the metrics of Hubert Dreyfuss to industrial investigation and the dicta of Müller-Brockmann to experiments in print publication would all be nestled in the Science faculty. The reason they are not is that none of the answers presented in traditional design disciplines are experimentally verified in the manner of a scientific thesis – rather than validating models of the world, they are at best good enough answers in an ongoing design conversation with ourselves. We all recognize the qualitative difference. Thus the presence of human factors metrics and best-practice guidelines is in fact a stamp of a covert design identity in the old HCI discipline. Fitt's law and Shneiderman's Golden Rules, for all their generic strength, cannot suggest what to plug into them. Like all metrics and guidelines, they are silent on the most fundamental of questions – what might we design, in order to have something to test or analyze? Finally, they also fail to consider another thought – that efficiency and adherence to protocol might not be the be-all and end-all of interaction.

Interaction design challenges any claim to primacy of HCI's scientific identity in questioning issues of interaction. Interaction design's assertion is that a purely scientific model is insufficient to the task of questioning how we might best work with computing devices. The question is a cultural one; as such a more designerly approach is necessary. Starting from this “ground of Dreyfuss”, a gradual expansion towards designerly thinking complementary to its existing scientific identity seems, in hindsight, inevitable.

An increase in the level and broadening in the scope of interdisciplinary thinking in interaction over the last 30 years is a matter of historical record. Where Doug Engelbart drew on psychology and linguistics, today's interaction design practitioner has a much wider range of possible inspirations. Much of this liberation of inspiration arises from the process of reconstruction of HCI into an interaction design discipline to which I have just alluded. Philosophical, poetic and scientific models vie for attention; the range of choices inspires a vast outpouring of possibilities. The temptation is to think that a smörgåsbord of choices is the mark of a strong discipline. The real challenge for interaction is now how to draw practice models themselves across boundaries and into the discipline, rather than simply cherry-picking ideas, concepts and structures with which to design. This idea, which is qualitatively different, is that interdisciplinary practice can be used to engage critique of the discipline's practices at a structural level. I will not talk about this in any detail at the present, as I will broadly come back to this point in the second half of this talk.

Finally, I want to consider the question of what we think computing *is for*, though I'm going to look at this in order to consider the benefits of the process of questioning itself, rather than in championing any particular answers.

A whiggish historical outline of interaction design would have interaction design commencing with the work of Sutherland and Engelbart, transiting in parallel with the development of the ideas of the personal graphical computer with networking via Kay and Xerox PARC, and ending with the establishment of the GUI as the default standard for personal computing, with a series of codas as we determine how to apply this GUI to new devices.

This becomes the story of interaction design as the design of technical apparatus of a particular kind and purpose. The field is of course much deeper than this. As the media forms of computing begin to coalesce, we find ourselves ever more engaged in a ongoing dialogue of construction. Artifacts enter the process as means to the end of interaction – punch cards, magnetic tape, the terminal, the keyboard and most of all written language are adaptations of existing technologies and methods into the structure of interaction. Later, the GUI sees a rise in native paradigms. Spatial reasoning becomes more important as artifacts virtualize onto the desktop. By virtue of our increasing familiarity with the problem field, we begin to determine paths unrealizable in any other media.

Our understanding of what computing *is for* therefore changes from electronic oracles computing answers, to dynamic media enabling interactions. Nothing has really changed about what a computer does – process boolean logic – but our context of usage has shifted incredibly through design discourse. Over the course of this shift the social focus of investigation has moved from the narrower focus of supporting computer programmers and technicians (as Engelbart did) to enabling computing in society both in general and in the specific (the GUI and onwards to targeted social tools).

Douglas Engelbart's massive rethink of computing would also lead to a radical reinvention of computing. Engelbart's collaborative system, NLS, made many breakthroughs, but eventually faded as its thought process was too restrictive and difficult to learn. Yet it offered several key insights. These were that psychological theory could be brought to bear on computing, that the human and machine could work in a embodied and communicative partnership, and that collaborative systems had significant advantages. These themes run through modern interaction design – in many respects, while not the first person to build such systems, Engelbart is its prototype.

Such views have lead to a radical upsurge in human communicative power, with considerable liberation of cultural energies. What we are witnessing today is the realignment of human activity – people inserting themselves into the communication system, constructing it with their own dialogues through digital media.

But the success of this explosion, and the shift it relied on, hides a salient point - interaction design does not simply mean how do we communicate with traditional personal computing, though computing itself has a vital role to play – amongst other potential actors. Personal computing is the vanguard of possibility of other dynamic interactive systems – some of which might have equally paradigm shifting possibilities.

The history of interaction design to date offers an alternative: tangible media. Whilst tangible user interfaces were being manifest in projects such as John Frazer's various architectural modeling systems of the 1970's to 1980's, and graspable user interfaces in the early 1990's, the field reached a point of critical exposure in the computing literature about ten years ago. This critical point was the publication in 1997 of Hiroshi Ishii and Brygg Ullmer's seminal *Tangible Bits* paper. As described by Ishii and Ullmer, a tangible user interface is an attempt to reconnect the world of materiality with that of the digital. As they said:

TUIS will augment the real physical world by coupling digital information to everyday physical objects and environments... which will change the world itself into an interface. We see the locus of computation is now shifting from the desktop in two major directions: i) onto our skins/bodies, and ii) into the physical environments we inhabit... We are focusing on the second path: integration of computational augmentations into the physical environment. Our intention is to take advantage of natural physical affordances to achieve a heightened legibility and seamlessness of interaction between people and information.

We can see here the fundamental points of concern for tangible interaction. These are coupling of the world with data, physical manipulation of material objects and processes, the nature of human embodiment, product semantics, and affordances. The usual result is interaction with & manipulation of physical structures as tokens. As Klemmer, Li Lin and Landay state in 2004, in a typical description of the domain: "Tangible user interfaces (TUIs) augment the physical world by integrating digital information with everyday physical objects. Generally, TUIs provide physical input that controls graphical or audio output".

The problem with current practice is thus laid bare: in choosing to work with everyday objects, very little actuation, if any is ever brought to bear. There is next to no consideration of making the structures dynamic in themselves; they are traditional objects, re-purposed with a little bit of RFID, as tokens for channeling traditional computing.

There are some notable exceptions to this trend, including the work of Tom Djajadiningrat and colleagues Stephan Wensveen, Joep Frens and Kees Overbeeke at TU Eindhoven, who take a perceptual-motor rather than data view of tangible interaction, and the work of Ishii's Tangible Media Group at MIT, in particular Hayes Raffle and Amanda Parkes' Topobo. I want to discuss this last in a little more detail, as it is of immediate relevance.

Topobo is a TUI project on the fringes of robotics that highlights certain aspects of this way forward, in a way that is suggestive for thinking about robotic material interaction models. This system represents a condensation, as a possibility space, of work on reconfigurable, tangible construction systems such as Frazer's Universal Constructor with the paradigm of children's construction toys. Topobo is a kinetic memory system, designed for ease of use by children. It featuring a demonstrative programming system, in which motion is demonstrated to the system, which information it then records and later plays back on command. One lesson is clear: if it is to continue to explore the possibilities latent in tangibility, interaction design must reach out to robotics.

As yet this isn't really happening on a large scale. There hasn't been much discussion of deeper possibilities for human-robotic interaction in the literature to date, although a major human-robotic interaction conference started occurring last year. Much of the talk in the literature to date has been in regards interacting with the kind of robots we are all familiar with; humanoid or otherwise biomimetic structures. As a result, we face interaction design opinions like the following from Buurman:

> "Robotics is to some extent a marginal topic for designers... one reason is that such machines

> function in environments created by and for people.... If we associate [cars] with a friendly face, we will certainly have to reevaluate such issues when designing robots. Other problems are linked to the design of our social environment, which henceforth may be peopled by mobile robots that take care of the elderly (e.g. Japan), dispose of garbage or work in factories. How will we experience such machines, how will we coexist and communicate with them, and on what emotional level will we experience these new circumstances? ...entirely new issues in man-machine interaction will become significant for designers such as the fields of gesture recognition and multimodal interaction (speech control)."
>
> Buurman, *Total Interaction [2005]*

Both tracing the genesis of these opinions, so that we may work around them, and locating avenues for enlarging the spread of tangible interaction, so that we may enrich practice, leads into a consideration of the robotic.

An outline of thoughts on robotics and self-reconfigurability.

Robotics, like many disciplines, also has a foundation myth which reflects its key conceptual structures. This myth sees it arising out of a posited long-standing cultural impetus to construct artificial life. The definition of the robot and the desire for its construction are argued as descending from a deep-seated, cross-cultural desire to create technologically-constructed artificial life. Lines of influence are usually traced from mythic creatures, such as those of Greek legend, to the magical traditions of the alchemical homonculus and the rabbinical Golem, through to remarkable automata such as exemplified by Edo-period Karakuri Ningyo of Hosokawa Hanzo Yorinao, Tanaka Hisashige and Benikichi Ono of the Japanese tradition, and those by Vaucanson and Jaquet-Droz in 19th century Europe.

Such machines are therefore seen as precursory attempts to realize a dream of technologically-constructed artificial life, which leads linearly to robotics, as elucidated in Čapek's seminal play, "Rossum's Universal Robots". This play is said to have kick-started thinking on robotic engineering in the West and Japan as the practical concern with construction of technologically-constructed artificial life, which continues to this day.

Unpacking this myth highlights several interesting assumptions that permeate robotics, and I would argue shape its agenda. It is ironic to note in passing that few of the mythologizing roboticists who discuss "Rossum's Universal Robots" seem to have actually read the play – as Čapek's 'robots' are more akin to Dick's replicants, being flesh and blood machines more in line with biotechnological practice than electromechanical.

It is also interesting to note that the automatist Vaucanson worked both on biomimetic automata and on factory production automation. As we will see, these two themes lie at the core of modern robotics.

This highlights some dilemmas of modern robotic practice – the morally ambivalent status of many traditional practices. I must necessarily talk in broad brush strokes here – there are exceptions, but the bulk of the work points in these directions. On the Western point, we see (outside an incredibly large military commitment in US research) an attachment of service robotics to the means of production, and its role in generating conditions of overconsumption. The robot is thus the 'morally acceptable' slave, in that it does not suffer its slavery as a human would; yet like all slave economies, this one fails on the desirability of the outputs of such a system – overproduction, joblessness and the idea of work as the province of repetitive drones rather than human cultural activity.

On the Japanese point we see a focus on entertainment, often to the point of relying on robotics for social cohesion. We can consider one project as indicative of this theme - a robotic seal for the elderly, to assist in their loneliness. Here we see the companionship model used to patch over deep rents in the social fabric; the idea that the elderly might have no social structure but for a robotic seal doesn't seem troubling. As Bartneck and Okada point out:

> “We are sometimes missing a discussion of the underlying assumptions of some of these robotics applications... we wonder if it is a good idea to sell a robotic pet to lonely elderly people instead of providing them with real social contact or technology that enables them to build up relationships with real people”
>
> Bartneck and Okada, *Robotic User Interfaces* [2001].

Across both areas we can see an unchallenged assumption coming to the foreground. Under this assumption, the primary conceptual structure used by engineers and designers to think about problems in traditional robotics is biomimetic. Simply put, this is an assertion that the context of a robotic system is that it is analogous to an artificial life-form. Biomimesis operates in traditional robotics in four general ways. These are firstly, biomimesis as it governs morphology; secondly, as it provides cognitive modeling for control structures; thirdly, and most pervasively for our current understanding of the robot, as it determines the cultural position of the robotic object as taking the meaningful place of a human subject (or other biological agent); and finally, as it defines such interaction as communication – between the human and robot, or human to human via robot – so that it may carry out that role. Overarching is the fundamental conceptual structure – the categorical assertion (following Rosch) that a robot *necessarily describes* an artificial life form.

Whilst robots of this kind have been intensely dominant in academic robotics practice over the past half century, they are not without problems nor are they logically necessary. We've already seen some of the social problems they generate, but there are technical issues as well. One major practical problem with such a robot is that it is just what it is, and no more. A computer is able to reconfigure itself via its display into any conceivable piece of software that can run on it, while a robot will always be the very robot you have. If it is physically unsuitable for the job, you need a different one. The fundamental insight from this is the consideration that an adequately self-reconfiguring robot could effectively become any other conceivable robot. Self-reconfigurability is the exploration of this problem. As I will discuss below, however, self-reconfigurability challenges the very core of the biomimetic stream underlying much of modern robotics.

A self-reconfiguring robot is any machine which can change its own structure. A primary goal of projects to construct self-reconfigurable robots, and in particular of recent proposals for robotic technologies such as massively parallel microrobotic ensembles, is to remove the limitations on structural generalization that current engineering approaches to robot morphology impose. In doing so, a primary aim is to generalize functionality. It is felt that a self-reconfigurable machine would have the advantage of being able to complete satisfactorily most tasks of a specialized machine, whilst being able ideally to become any other known machine. A wide range of self-reconfigurable systems of various capacity currently exist, either in built form or as simulations.

Adding more units, and decreasing their size, increases the possible resolution of the solved graph structure. With this increase in resolution, complex arbitrary forms in a lattice, as suggested by several projects, therefore become a conceivable and understandable outcome of current research in self-reconfigurable robotics. At this point, it can also be observed that the ensemble thereby defines its possibility for modeling any spatial form, limited only by its nature as an embodied, physical system. The end result is effectively a shape-shifting robotic system.

Several surveys of the field exist; the second chapter of Keith Kotay's Dartmouth College PhD thesis, “Self-Reconfiguring Robots: Designs, Algorithms, and Applications”, contains a strong overview of the state of the art as it stood in 2003, and is freely available online. This year's IEEE Robotics and Automation paper by Yim et al., “Modular Self-Reconfigurable Robot Systems: Challenges and Opportunities for the Future”, updates this chronology to early this year. I won't therefore go into too much detail describing this area's varied output; instead, I want to highlight the issues faced through some key projects.

Self reconfigurability in robotics starts nearly 20 years ago. In a 1988 paper titled “Dynamically Reconfigurable Robotic System”, Toshio Fukuda and Seiya Nakagawa talked of a prototypical machine composed of heterogenous components, that could ideally reconfigure its shape to suit a task at hand. The canonical example of the utility of this newly-proposed kind of system was of a cleaning robot able to enter the narrow neck of a storage tank and restructure itself to then clean appropriately. This example highlights the initial impetus of reconfigurability – how to make the monolithic structure of traditional robots more flexible, in order to expand their domain of application. Many of the other key ideas of the discipline also appear here – issues such as the level of the flexibility and adaptability to changing tasks, the heterogeneity versus homogeneity of parts, control and structuring methods, the possibilities for self-repairing structures, optimization of structure for tasks, and fault tolerance.

The discipline began to pick up steam in the 1990's. Whilst still a small subgenre of robotics, a number of projects by key investigators, such as Satoshi Murata, Mark Yim, Daniela Rus, Wei-Min Shen, Greg Chirikjian and Hod Lipson, explored the issues outlined in Fukuda and Nakagawa's work. Yet most of these projects were large, bulky and slow to reconfigure. There were also problems of cost and fragility, both of units and of systems. The fundamental question was, and still is, who can build a stable working system of more than 50 units?

With these technical difficulties, much of the best work done in this field has therefore been virtual. A team centered around Mark Yim at Xerox PARC explored issues of reconfigurability in a rhombic dodecahedral system, relying on simulation to validate algorithmic efforts. In doing so, they were able to display not only shape-shifting, but dynamic reconfiguration in response to interaction. Butler et al. [2004], working with Daniela Rus demonstrate transformation of an ensemble system in space using cellular automata techniques, using a variety of actual reconfigurable systems. Implementation remained, and remains, a technical problem.

It would take a group of computer engineers from outside the robotics field to begin a reconfiguration of our understanding of the domain. In 2004, the Carnegie Mellon/Intel Claytronics project set an agenda to represent arbitrary structures believably, through use of massively parallel microrobotics. What this project was saying was, that previous work had been building at too large a scale, and with the wrong kinds of connectors for dynamic reconfigurability. Whilst it has built some ground-breaking prototypes, which reconfigure with factor of ten increases in speed, the Claytronics team primarily undertakes simulator work prior to developing its own micro-scale machines. Recently, a new language, Meld, has allowed simple logic programming to shrink Claytronics control programs by a factor of ten. However, complex controlled shape transformations still pose fundamental difficulties.

As we can see, it would therefore be unfair to suggest that this field is approaching maturity. Certainly the technical capabilities in this area are nascent, not surprising given its peripheral position in robotics, and the difficulty of the task attempted. This is a development issue, but one that threatens the field in a social rather than technical sense. None of the technical outcomes proposed are interdicted by any physical law, but social patience and funding may run dry. As a result, we mustn't get too ahead of ourselves in thinking current technical solutions are stable enough to expect such systems in the field soon. There is danger in the “VR effect” where a discipline's initial claims run well ahead of its technical capabilities. Managing expectations, whilst building a project community, will therefore be critical, and much can be learned from interaction design's experience with VR in this regard.

Despite the identification of scale and connectors as problems to be solved, other problems remain outstanding. Optimizing for modularity means sacrificing other optimizations. The machine is never as good as a purpose built machine – it can never be as optimized for its current purpose as the dedicated hardware – this is the software issue, that virtual machines don't run as fast as real machines. A purpose for systems must be found that leverages modularity.

Interaction with such systems has not generally been considered except in the broadest terms. This is also true of traditional robotics as well. Robots have been understood as biomorphic communicators for some time. Note that often HCI also framed computer interaction in terms of human-computer communication. This is not the only path, as tangibles have demonstrated.

These two points lead to the most fundamental problem for self-reconfigurability, one that is posed by the discipline itself. It is inherently an interaction problem. For me, this is the spur to designerly action:

> “Many of the researchers developing this field [self-reconfigurable robotics] have determined that finding an application that clearly drives the need for these systems is one of the major challenges.”
>
> Yim et al., *Modular Self-Reconfigurable Robot Systems: Challenges and Opportunities for the Future,* 2007.

For design, it's inherently a question of social context. In other words: how are we to conceptually structure self-reconfigurable robotics, so that we may define spaces for application development beyond those traditionally identified areas?

As I will argue below, self-reconfigurability allows for a new concept of the robotic. This is the idea that a robotic system, rather than a biomimetic structure, might be a media form. This reconsideration of robotics, which is foregrounded in Claytronics, suggests that the domain of applications being attempted are not appropriate for self-reconfigurability, and reconsideration of the domain might suggest alternate technical outcomes.

Here lies the importance of the fundamental insight of the Claytronics project – that rather than supporting shape-changing robots, self-reconfigurable robotics could instead be the grounding of a spatial media form. It provides a ground on which a native approach to self-reconfigurable robotics could be grounded, rather than importing the problem set from monolithic systems. In a nutshell, the problems of monolithic systems inspired a solution which turns out to not actually be a solution, but rather something entirely unique, with its own set of application domains that are quite distinct from those of traditional robotics. So, rather than dig harder in traditional robotic spheres, let's consider what alternate modes of activity and social contexts we might benefit.

Reconfigurations of robotic interaction considered.

My own work turns on exploring, through design practice, what these application domains for reconfigurable robotics might be. Much of the work is based in the speculation of engineers; in many respects it seeks to extrapolate possibility rather than provide actuality. In many respects this is a polemical move, aiming at arguing for particular kinds of technical research within the community. I make no apology for this; I consider the role of speculation and polemic, as I will discuss later, as central to the task of designing and leading forth technological structures. Naturally, I can only work at a very broad, low level, and cannot offer any certainty that ideas developed will be the ones that succeed culturally. What I can do is offer pathways – that, in the end, is all any purely speculative or visionary designer can do.

I will begin by pointing out that accepting the system's identity as a modular system is the beginning of resolving this quandary. One must work with what one has. Rather than consider the optimization issues as a problem, let's instead use them as parameters for the search. In other words, our role for self-reconfigurable robotics should lie in a domain for which optimization for modularity is a benefit.

Self-reconfigurability therefore forces a reconsideration from modular morphology. It is obvious that biological structures, with their focus on heterogeneous components down to the cellular level, are not appropriate. In answering this, Claytronics looks to representation. An ensemble's modeling and rendering capability shows that they can be considered as forms in a representational media, instead of biomimetic structures. That is, rather than see the modules as cells, we see them as physical pixels. This is a path which, whilst it promises some powerful applications, treads a precarious technical path. While I think there is some validity to the idea, and certainly provides a strong context for application development, I consider it a problematic model as currently conceived for at least one major reason, beyond the current technical problems of achieving dynamic, arbitrary representation of moving objects, and issues involving the algebra of representation.

While dynamic arbitrary representation may prove fiendishly difficult, it could also eventually be solvable. A far more potent reason I think that this line might be unprofitable as a primary context, and one which does not turn on particular issues of technical implementation, is that *media* as a concept does not necessarily imply any conceptual scaffolding for thinking about the system – there is no structural paradigm inherent in *media* for helping engineers manifesting patterns in the ensemble, or designers who wish to develop applications. In other words, the means of description do not naturally unpack using a conceptual scaffold.

Scaffolding is vital both for engineers wishing to structure technology development, for designers developing applications, and for users needing to construct mental models of the system. Object orientation in the Smalltalk GUI provides an elegant example of this in action. The scaffolding provided for engineers by biomimesis is one of the reasons why it has been so influential as a design paradigm in robotics to date; it provides a way to think about the problem that unpacks naturally, and is generative of ways to think about problems at many levels of the system. Considered from the designer's perspective, it is suggestive of communication-based robotic user interfaces. Users may understand it as an agent in the world. Media provides no such scaffolding for robotics, due to its highly abstract nature as a concept. There is no particular manner in which media are constructed; although if we consider how particular forms of media are physically constructed *as materials*, we will derive other, richer conceptual models that promise to meet this scaffolding requirement.

This lack of an overarching structural scaffold may be one reason why Claytronics, like so much of reconfigurable robotics, currently suffers from a "bits and pieces" approach to applications without a guiding design framework other than technical achievement in engineering. Despite a media framework for conceptualization, some of the applications rendered in this media form are variations on traditional themes of biomimetic robotics, such as the virtual embodiment of medical and rescue personnel. The remainder – true media applications such as synthetic reality – are novel, but do not suggest any inherent form of interaction, and are more reminiscent of passive media such as television. The most recently published idea, a 3D fax machine based on casting the transmitted object in a Claytronics substrate, provides a practical and achievable goal for first generation Claytronics, and contains within itself the seeds of a an alternate approach. I would argue that it is here that Claytronics has moved from speculation towards applications of value.

This alternate path, which I am currently investigating, is that of materials. The results of this inquiry, necessarily scattered as they are through the design research process, can be summarized simply. A robotic system, capable of shifting its form arbitrarily, of being modeled according to physics and material simulations, and being suitable for tangible interaction, can be designed as a general form-giving media – as a *material*. Rather than as cells, or physical pixels, we see them as means of representing discrete models of material processes. A system of this kind is not a media in the limited sense that recent virtualization of traditional media might suggest, despite its digital character. Rather, it is media in the broader sense; robotics as a computationally enabled tangible media, as a plastic substance capable of interactive play. Robotics can thereby be understood as a means to embodying computational interaction in a new, challenging and productive manner; as stuff with which people can do things. In doing so, we must reconsider what we mean to achieve when we design a robotic system.

In proposing the context of *robotic materials,* the proposal I will describe in this paper is one which answers the social context issues raised above. According to this proposal, rather than following the traditional path of structuring robotic systems as biomimetic subjects thinking and acting in the environment, we would instead structure our self-reconfigurable robotic systems as *materials expressing dynamic interactive properties*. As robotic materials, they would have the added advantage of deep programmability and thereby transformative and unusual substance. From this point, a range of applications embodying this deeper paradigm shift will follow.

In order to understand how a material paradigm might be fundamentally different to a biomimetic one, I would first pose a small but powerful question as a thought experiment:

> *How might one imagine a programmable robotic fluid that can run up walls?*

The initial cognitive dissonance this idea provokes is challenging at first; trying to imagine how a robotic system might implement a controllable material simulation that defies laws may seem to run counter to many ideas we presently have of the definition of a robot. But exploring dissonances such as these is my point of departure.

Systems developed to date almost always assume some level of biomimesis in a robot, even if only in its social context of replacing a human agent, and for many existing applications this is appropriate. Yet robots are not inherently biomimetic *qua* robots. If we were to consider self-reconfigurable robots purely as embodied spatial systems, then one could equally be defined an embodied, dynamic spatial computation of some form of graph structure. This does not immediately imply biomimesis, although it can be supported. One alternate description suggests a third might exist. An approach based in materials emerges as an alternative conceptualization, and new applications for self-reconfigurable robotics in entirely new domains of robotic activity become apparent.

Material simulation, as both a structure and interaction paradigm for robotic media, offers a point of departure from the traditional purpose of robotics, which has been fundamentally concerned with the mimicry and replacement of the biological agent. It is suggestive, not just of vastly different ways of structuring robotic systems for engineers, but also of different means of using and conceiving of them for the average person – ways which might extend and integrate this branch of robotics with a large area of human technical and social knowledge concerning the arts and crafts of making, collaborative social work, and materials as used in industrial manufacturing. Defining this difference and its complementary integration into technical culture, we will be able to develop a native approach to self-reconfiguration which is suitable for exploring the inherently spatially transformational nature of the technology itself.

Considering the reconfigurable ensemble as a thing in the world requires us to assert a technical context that accounts for its arbitrary morphology, its capacity for self-organization, its tangibility, its materiality and its possibility for conceptualization as a means for constructing artifacts. Setting up a context of robotic materials meets these requirements. Materials themselves have arbitrary forms, composed of micro-structures. There is no global shape of steel, or wood; rather, there are steel and wooden objects fashioned by humans directing energy into the martensitic and cellulose micro-structures of materials, such as raw iron and carbon or raw trees, whilst being conscious of the global structure as feedback system. Robotic materials require control structures; like natural materials, these will not be hierarchical but instead emergent, low-level systems. Like all materials, robotic materials will be physical, imparting tangibility and able to be used for creating artifacts of various kinds. Yet they will have a difference. They will be inherently robotic materials: the thing that will set them apart from other synthetic materials, like nylon, will be their inherently programmable nature.

The robotic material promises a culturally revolutionary effect potentially equivalent to the combined introduction of plastics and computing. Being physical ensembles, robotic materials may interact internally and with the environment. Being computationally controlled, they may *alter* the manner in which they interact as required. Being tangible, our manner of interaction with them is inherently embodied.

A general category of robotic systems conceptualized as materials proposes a wide range of possible utilities in human technological activity. It may serve as material for the instantiation of transformational objects, for providing transformational components in other, not necessarily robotically-conceived systems, and also as a new medium for creative activity in itself. A new and broad range of applications could therefore be identified in engineering and media production. Robotic materials promise to provide a *context* that, to extend the words of the relevant engineering community, “...clearly drives the need for these systems”.

One technical problem for which a material perspective seems promising is that of control. Control systems are traditionally the primary source of difficulty in robotic systems. Control is the means by which the system maintains its internal relations between parts. In traditional monolithic systems, this has been the means by which a robot controls its body. In a self-reconfigurable system, this is the means by which various modules are rearranged. Traditional machines have used models based on biological structures, such as neural nets. Some form of biomimesis is normally used in self-reconfigurables as well.

Yet the manifestation of structured patterns involving dynamic spatial transformation is not unique to biological systems or mathematical models. In 1967, the Swiss pharmacist Hans Jenny documented, through photography, the vast range of spatial patterns that can be expressed through standing waves in colloids and granular materials. Generative systems have been used in a wide variety of design and arts applications, from architectural composition (Frazer) to music and painting (Galanter). The literature also points to work on self-assembling fractal structures in molecular engineering, self-assembling algorithmic structures in amorphous computing, and a wide variety of other complex systems which manifest structured, dynamic pattern without using cognitive models. We can continue to add examples from the study of complex systems, but the point has been made. The material world provides other models for spatial structuring besides the biological. The practical question becomes how to apply these models to robotics in a fashion that suggests a strong, constructive paradigm for robotic system design.

One possible answer arises in models deriving from physics and material systems. Recent work by William and Diana Spears with co-workers at the University of Wyoming, which has been well documented for nearly seven years and is available from their site, demonstrates the capability for swarm robotic systems to structurally organize themselves as a molecular dynamics system, without inter-unit communication, according to local rules based on Boltzmann equations. These swarm units position themselves relative to other units, using only local force vectors drawn from their internal rule set and distance sensor readings of nearest neighbors' locations. As a result of their rules being based in physics models, they are able to manifest a natural representation of a range of material structures based on the modification of the constants defined in the equations. If the gravitational constant of the rule set is raised, their swarm structures spontaneously manifest crystalline structure as close packing lattices, liquids as fluid motion of units around each other and gases as randomized motion of units on linear vectors within a containing space. These shifts occur spontaneously, from self-organization, with clearly discernible phase state shifts at each transition.

The Spears note several advantages to their approach. The first is that complex behaviors can be obtained in the real world from the simply-modeled local interactions of physics, which suggests that a robotic analog may be likely. Other work by Bojinov and Yim at Xerox PARC points toward the same conclusion. The Spears note that this approach would benefit smaller systems with necessarily simpler sensing equipment. The other advantage relates to scalability of control algorithms. As the Spears stated in 2004, "...since the approach is largely independent of the size and number of robots, the results scale well to larger robots and larger sets of robots". The final point, which will be of interest to those contemplating grand challenges in self-reconfigurable robotics, is that physics also promises the possibility for self-organization, fault-tolerance, and self-repair in complex systems – without a necessary biomimetic framework.

Whilst the current embodiments of these systems only scan for neighbors and obstacles, there seems no immediate reason why an adequately engineered system could not also adjust its constants from information in its surrounding environment. Such a system would therefore be a model of a *programmable material process*, rather than a model of a living thing. Its agency would be internalized within the ensemble; it would consist of how it managed its own part of internal structural relations. The result would be properties, rather than traditional agency. The key will be determining if such approaches can be transferred from swarms to self-reconfigurables, which do not have the luxury of long term disconnection from the ensemble under current Claytronics models. As some reconfigurable systems have already used cellular automata for locomotion control, and given there is a literature of cellular automata simulations of physics, this area looks promising for future research.

But why undertake this? In doing so, we engage one of the great failings of modern interaction practice in the general domain – that it remains locked into a single model of technical embodiment, namely the screen and input devices.

Many domains of technical and cultural activity remain, in which interaction design using computing has made limited inroads. One such class of activities is the act of spatial modeling. In part, this is because spatial modeling requires working with materials.

In activities such as these, practitioners' cognitive skills in the manipulation of material substances form a considerable segment of the body of knowledge. Spatial design is explored through doing. This is an area for tacit knowledge and interpersonal interaction.

Traditional computing does not address this practice in its native spatial vocabulary. Current systems cannot effectively deliver tangibility in the spatial modeling process, nor deep co-operative modeling in groups. Working by touching data is presently deeply mediated. *Pax* Shneiderman, but working with a mouse on a screen is not direct manipulation – currently, it's more like working with radioactive substances. While haptics and VR promise much, they do not have the actuality that enables their digital constructs to be things in the world whilst the design process is occurring.

The proposal of a context of materials might go some way towards thinking through how we can answer these problems. Fundamental in this is the insight that a material has no necessary form, so it is actually properties that matter. Form is determined by the human interactor, acting in collaboration with the system.

But materials might not just operate as a means for structuring the system: they may possibly also operate as a means for reading the system itself.

I want to introduce you a little known principle in interaction design, one that for want of a better label I term “the Coyote principle”. This is the comprehensibility of representational systems based on a mutable physics. This is not physics in the sense a scientist would take it; rather, this is physics in a game engine sense, as part of the textual structure of the medium.

In a cartoon, everyone knows that the representation of physics is part of the narrative structure. Characters are expected to walk along the ground and get wet in water. But every child also knows one critical fact: that the coyote doesn't fall until he realizes that he should. What this points to is that, in representations of physics, a natural physics is suggestive of unnatural physics, and that unnatural physics can be understood as part of the narrative if there is a consistency to its presentation.

A range of interaction systems employing artificial, qualitative and subjective physics already exists. Bedersen and Hollan's work in zooming user interfaces, now coming to fruition in recent Microsoft prototypes, was based in an understanding of this potential, as is the interaction physics of operating systems. Any Mac user is familiar with the physics of minimizing windows to the Dock; here on Windows XP, I can demonstrate less.

Thus I come back to the idea of robotic water that flows up walls – of mutable digital materials, taking advantage of the narrative structure of their own so-called physics.

Through this section, I have revealed an underlying context of dynamic tangible media, constructed through robotics and understood as digital materials expressing mutable properties. Such systems will inevitably be tangible, and perhaps in a sense closer to Ishii and Ullmer's original intent. This was close coupling of the actual physical matter of the object with the computational process – rather than an interface, a computational object or process. In many respects, this idea foreshadows and underlies the concept of robotic materials. In a tangible system, interaction is with the computation itself embedded in the physical object or process. Regarding the kinds of interaction possible, Topobo might offer some clues. Whilst it is commonly used by children to imitate living structures, this is arguably not an essential aspect of system design. Its interaction model, of direct physical manipulation and recording of movements, provides one practical basis for further thinking about how we might work with a system of the kind I am describing.

Engaging my problem through architecture and philosophy.

Now, it's time to go behind the scenes. One thing that academics often discourage is showing the workings and wires – the idea of the impression-value of the fully formed theory is very strong. But this does considerable injustice to the process of creative development of ideas, hides how academics actually think, creates illusions of logical consistency that betray the qualitative nature of much practice and denies that the process of creativity is as important as its outcomes – a thing-centered view. In this section I will reveal some of the props to my thinking.

I began by questioning tangible interaction problems involving spatiality. In doing so, I was seeking very simple metaphorical structures to provide answers to technical problems of interaction. My work felt insufficient – and seemingly vacant. What was the purpose of this work? And how could undertaking it improve my approach?

During my process of self-analysis, several pathways became apparent. The first, and that which led directly to my current field of inquiry, was that I found myself inexplicably fascinated with the existential nature of the scroll bar button in the MacOS X system I was using for drafting my writings.

Looking at the Aqua scroll bar button, I found myself temporarily unable to work onwards. I was stuck on a question that had appeared unbidden in my mind –

> *"What is that scroll bar button MADE of…?"*

This was a question that I could not immediately answer (nor would it cease repeating itself in my head), so I canvassed a range of friends, colleagues and strangers informally for their opinions. I got a range of responses, from *pixels* and *pictures*, to *data* and *classes*. As I asked, I began to notice that the answers touched on one of two basic categories – form or information.

What suddenly struck me, and what has informed this project since, was the realization that no-one had really considered the scroll bar button as though it actually *were* the kind of unnatural physical object it was simulating, nor had anyone answered my question by suggesting any type of material substance from which such an object would be made. This was despite the obvious visual references to material composition in its mimicry of the color and reflective properties of (what appeared to me to be) gel toothpaste. It seemed that in some way, the scroll bar was made of something, and that something was an unnatural transformative material.

The second, due to a critique of my work by Jeff Malpas, was that I was not thinking about the problem, instead I was looking for neat answers. To do so, I would need to re-engage with philosophical thinking, which I had let lie dormant since completing my arts degree a decade previously.

The literal embodiment of Derridean philosophical thinking in deconstructivist work brought up several issues. These key themes were 1) the nature of cognition, and how this relates to our idea of a computer, 2) issues of authorial control, political activity and ethical commitment and 3) the nature and role of materiality.

First, the Boolean logic gate and the mind body split. Whilst this project was still operating inside the confines of traditional computing, the thing that I had noticed quite strongly in my readings of computer science and artificial intelligence was the manner in which neo-Cartesian models of cognition had ensconced themselves. The very hardware-software nature of computing seemed structured by this influence. The modern computer can be seen to embody a Cartesian split, wherein the physical hardware represents the supporting body, and the transient, intangible software the mind. Traditional Strong AI itself is predicated on the idea that mind is a form of software, which can be replicated in programming.

Yet at the same time, I discovered other themes that talked away from this point. Staring with Bergson, a range of phenomenological thinking through Merleau-Ponty has engaged with issues picked up by interaction design. These issues became more relevant, and these philosophers more prominent, as I moved towards tangibility. Issues of the embodiment of human beings, drawing on both this and Heidegger's concepts of ready-to-hand, have permeated general academic writing in the field over the last five years. Key in this movement was Dourish's “Where the Action is”, although both Coyne and Winograd had introduced Heideggerian concepts in the preceding decade.

One of the problems with philosophical work in this area is that it is so often compromised by its reliance on the scientific models of the day. Looking for more timely, yet scientifically supportable and nonetheless stimulating models of cognition, consciousness and creative thinking led me to the Radical Constructivists, a post-Piagetian group centered around Ernst von Glasersfeld. The idea of an ongoing process of the construction of understandings espoused in this work was central to my observation of the Coyote principle in traditional interfaces, and helped to explain why such an effect might be observed.

But one question still remains after all this: what about the embodiment of the machine? How does all this reconsideration of embodiment translate to the machines? This is one avenue that remains unexplored. Too often, interaction designers talk of the embodied actor, then accept technology as a given. What might alternate embodiments of computing be like. It was here that I began to seriously question the structure of computing, and realize that a radical reconfiguration of the structure of a computing system was necessary for opening the door to new possibilities. Rather than talk about the human, we needed to face the mind-body split we had built into the machine. A system that was both software and hardware was needed: the result, a search for a robotic materiality. At this point my work became clearer, yet murkier, with the arrival of Claytronics.

Second, the issue of the relation of technical systems, authorial control and democratic ideals is a subject that, more often than not, has troubled me. Interaction design practice quite happily quotes Heidegger's monumental "Sein und Zeit", drawing from it the concepts of ready-to-hand as means of analyzing interaction. Yet it seems that the community stopped there. And (apart from the incomplete status of that text) that troubles me, as there is a range of material that Heidegger wrote after the Turn, which might give practitioners something to really think about.

Heidegger' work in general is defined by a particular philosophical engagement with the nature of Being – the underlying nature of existence prior to our naming of things in the world. This essay continues this inquiry through a consideration of the unique ways of thinking that underline technology. In describing the nature of technology, *The Question Concerning Technology* expounds upon the related concepts of the *standing-reserve*, a status conferred on those aspects of Being that have been subordinated to mankind's instrumental requirements, and *Enframing*, a process of destiny that 'sets upon man to order [aspects of Being] as standing-reserve'. Standing-reserve and Enframing are seen as aspects of *challenging-forth* – advanced technology's default manner of revealing – against which Heidegger positions a crafting mode with its concomitant manner of revealing, *bringing-forth*.

Whilst Heidegger himself, in works such as "The Question Concerning Technology", was not so much concerned with environmental degradation as with cognitive degradation, his work is adaptable to sustainability and environmental thinking. The environmental impact of microrobotic systems will need careful management. Several possible problems face robotic materials. Units which escape into the biosphere run the risk of being pollutants, while successful inclusion of a technology of this kind into a culture may increase total load on power generation. The manufacture of units must therefore take account of the latest technological advances in green electronics and the minimization of power consumption. Recent thinking on this issue focuses on the idea that product life cycles need to avoid what is termed a cradle-to-grave model, in which objects must either be disposed of, or undergo what is termed down-cycling [McDonough and Braungart 2002]. Rather than making objects in such a way that deconstruction is not possible or that only the degraded recycling of down-cycling (such as turning plastic bottles into rough bulk plastics) is offered, a cradle-to-cradle model would require complete recycling of all aspects of the system. This demands that safe, organic decomposition of lost units must be developed (or their ability to be traced if this path is not technically feasible), and that units must be able to be easily deconstructed and their component materials reused with minimal toxicity and power usage.

The sustainability of robotic materials cannot be considered simply a series of dangers. There are also possible advantages that may accrue. Given that robotic materials would have transformational capacities, one advantage appears to be that objects (such as electronic devices) could be manufactured from this substrate rather than from natural materials. Ideally, they could therefore be reconfigured into another device and then back again using the same lump of matter. Their functionality could be manifest as a virtual device running in massive parallel on the units themselves. The possible ability to minimize manufacture of existing objects through virtualization of materials as mentioned above, especially in the electronics sector where interactive function can already be virtualized as software, promises a broad range of interest in self-reconfigurable technologies. They promise a range of physical software applications that maximize our use of natural materials while offering the advantages of distinct, function-designed objects.

But there is a final danger in this to which Heidegger has alerted us, and which interaction has not clearly considered to date. This is a more fundamental concern – the idea of the standing reserve. Interaction has paid this issue no heed, and undertakes the normal cheer-squad support of new technology for its own sake. Weiser's vision of ubiquitous computing was challenged on these grounds, and was quite clearly shown to be lacking. The reason – in the end, it was shown that the proposal to undertake ubiquitous computing was simply made because the technology enabled us to do so. Undertaking a Heideggerian analysis, Araya found there was no real need for ubiquity, other than tightening the grip of technical structures on political control.

In many respects, microrobotics capable of forming arbitrary form are in theory the archetype of the standing reserve. In practice they are not so threatening. Yet the issue of standing reserve still remains: are we making these systems in that image? How can we work against the power of Enframing, or can we? If we allow open-sourcing of development, are we enabling Enframing? These are questions which trouble me now, and to which I presently have no answers. Perhaps a means of exploring bringing-forth in robotic materials, through crafting, following Malcolm McCullough's exploration of digital craft in his text “Abstracting Craft” will help to resolve this issue. I look forward to reporting back once I have managed to get my head around this.

Third, the idea of materials forced me to consider their status, both ontologically and aesthetically. There isn't much to be said about materials at all. As de Landa points out, there is a lack of thinking here, not only in philosophy, but strangely enough in classical sciences. The vast majority of understanding that we have about materials derives from practical work undertaken by those working with materials – tradesmen, smiths, founders, ceramicists, woodcarvers and the like. This insight has led me to a stronger involvement with the body of material sciences, looking for inspirations and clues.

One recent ontological inquiry that has begun to bear fruit is to begin to think in terms of processes, following process thought as a stream. This is not simply to read Whitehead – there is a strong body of work from the Pre-Socratics onwards, through such luminaries as Leibniz, Bergson, Pierce and arguably some aspects of Heideggerian thought which approach the field. There is also a strong Eastern tradition centered around Buddhist notions of the transience of structure. The fundamental insight which seems to be arising is that this body of work will support thinking about materialities as a dynamic process, rather than as static objects. This strand, which is developing in my thinking, is an example of inspiration in an opposite direction, as it arises from considering the structure of ensembles and leads me to a body of work. Again, I look forward to what may come of this inquiry in the near future.

The final pathway I took was looking to architecture, in this case for practice guidance. Two primary points guided me here. The first was proximity, as I was located in SIAL, in a School of Architecture, and thus had plenty of possible mentors. The second was a realization of the depth of practice in architecture, which had already spent many thousands of years of dealing with the kinds of problems I was realizing that I had.

What does architecture do well? The two things that mattered to me from an outsider's perspective were that as a discipline 1) it looks outside itself, and 2) it looks beyond itself.

In looking outside itself, it engages with philosophy and other practice communities, such as engineering, on a regular basis. Looking at architecture as an example, I saw the spiral of architecture and structural engineering through culture critiqued by theory. This gave me confidence to begin working with engineers in a discipline with which I was unfamiliar, and to embrace my philosophical past rather than run from it.

In looking beyond itself, architecture engages speculation. This was deeply influential in my thinking. In speculative practices, architecture is future-binding. A speculative practice in many respects can be a message in a bottle, dropped into the sea of design thought, the effects of which will not be known in their entirety for many years. Yet such messages are seen passing by, and influence the nature of work undertaken today.

It should now be clear why I was so careful earlier to separate interaction design from traditional scientific practices. Whilst a certain level of speculation is central to modern theoretical physics, speculation often finds short shrift in some circles. Its central role in human creativity should be quite rightly understood and supported in mature design practices. But this is not always well understood or supported.

As an example of this speculative practice in architecture I will consider the influence of the visionary activities of the German author Paul Scheerbart within the context of the German Expressionist and Glass Chain, and therefore on 20th century glass architecture in general. I have focused here on Scheerbart as his trajectory, I found, parallels mine in many respects as a designer considering the presently unbuildable.

The visionary writings of the German author and poet Paul Scheerbart have a particular place both in the rise of the use of glass as a structural element in modern architectural practice and the relation between architecture and visionary thinking.

The author of numerous tracts, novels and poems, Scheerbart's literary output covered the social impact of a range of technological topics, from the possibility of aerial warfare and mass bombardment of civilian structures, to perpetual motion machines. His championing of glass as a building material, combined with his vision of reconfiguring the world order through transparency in architecture, was deeply influential on the design of the built environment during the twentieth century.

Banham identifies the importance of the Expressionist movement as a basis for the rise of glass architectural trends. It is in this context, as 'glaspapa' of the Expressionists, that Scheerbart's influence becomes apparent. As Bletter notes,

> "German Expressionist architecture consists mostly of rapid sketches, written programs, and publications. Paul Scheerbart's writing, which reveals a compelling architectural vision, is crucial to this work"

The work of particular concern to this discussion is the polemic *Glasarchitektur* (Glass Architecture), published just before the outbreak of the First World War. *Glasarchitektur* was the summation of Scheerbart's long term agenda to popularise radical building techniques. His previous works, mostly (to quote Banham) "...contra-science-fiction, astral pantomimes, moon romances astral novelettes and what-have-you" differed greatly in tone from this last masterpiece. The theme of glass as a transformative substance remains a constant thread; in the earlier works this theme tends to mysticism, while in this last work it offers an optimistic, practical and (though Scheerbart himself rejected the term) utopian programme for the renewal of human culture through architecture.

In this short and technically-oriented work, Scheerbart expounds on the social context of a proposed change in architecture culture from a brick-based paradigm to a glass-based paradigm, the social benefits he asserted would accrue from this shift, and the concomitant technical requirements for making this shift. For Scheerbart, this architecture represented a means to illuminate and transform, to use the qualities of glass as a means for effecting social change through architecture. It is Scheerbart's particular genius to interpret technological possibilities in terms of social construction:

> "We want no more walls that totally segregate us from the outside world, as was the case with the old walls made of bricks. We want instead double walls of glass, scintillating with color but also transparent, we want to install them everywhere, but first of all in public buildings. We want walls that do not isolate us from the boundless outside world. That which has no boundaries is the greatest thing of all. Let us never forget this. And that which has no boundaries is the immense space of the universe. From it we no longer wish to be separated. And so we want glass architecture to triumph over all the rest."

So pointedly accurate were many of Scheerbart's predictions concerning the future of architecture in the context of glass that the critic Reyner Banham states, in his *The Architecture of the Well-tempered Environment*, that "…this book has the greatest impact nowadays as the concrete and tangible vision of the future environment of man." Whether it has also had the social effect Scheerbart intended is open to question.

If Scheerbart were simply a visionary, who promoted a daydream of construction that turned out right, there would be little point in considering him. But Scheerbart was not simply sensitive to cultural meanings and poetic fancies; he was also carefully watching technical developments in architecture. Constructed historical precedents for Scheerbart's glass architecture had appeared structures such as greenhouses and exhibition structures as early as 1837, with the appearance of (later Sir) Joseph Paxton's Great Stove, built at Chatsworth for the sixth Duke of Devonshire's exotic plant collection, and the Kew Gardens Palm House, designed by Paxton's assistant Decimus Burton with Richard Turner and completed in 1848.

Scheerbart was certainly aware of these practice examples concerning greenhouses and was capable of extrapolating from them. He notes in Section III of *Glasarchitektur*:

> "We already have glass architecture in botanical gardens. The Berlin-Dahlem Botanical Garden shows that completely impressive glass palaces are already presented."

He was also clear on their faults as examples as well. He states, in criticism of these structures against his own vision of transcendent architecture, that:

> …the colour is missing."

Scheerbart was also well aware of Paxton's Crystal Palace of 1851, which in many respects is a clearer forerunner of the future of glass architecture. The Crystal Palace played a different, and in some ways suggestive role in English culture to Paxton's and Burton's greenhouses. In its role as an exhibition hall, it drew on its unique architectonic structure to serve cheaply and effectively as backdrop the vast array of curiosities and exhibits within – yet it eventually played more than a supporting role. Not only proof of scientific progress, but also "…a prophecy of humanity's glorious future: the Crystal Palace served as a promise of ultimate enlightenment" [Katz 2002] which eventually overshadowed the contained Great Exhibition in the public's imagination.

These early examples of glass architecture were not considered by the contemporary architectural practice as extensible to the general building tradition, but are instead seen as fancies - special purpose structures, in which the manner of construction from glass and ironwork played a very particular role in their functioning as controlled-climate garden environments for wealthy and aristocratic clients. Scheerbart's genius was the creative re-interpretation of existing forms in special purpose buildings into that which they *could become* on a more general level.

The effects of Scheerbart’s thinking on architectural practice can be traced in several ways. Most directly, we can trace his direct impact on German Expressionist architecture. As Bletter comments,

> “Scheerbart's work fundamentally influenced the architecture of his close friend Bruno Taut, whose position throughout the period of architectural Expressionism in Germany was pivotal and commanding.”

Glasarchitektur as Scheerbart imagined it briefly materialized in his collaboration on Taut’s Werkbund Glass House of 1914. This pavilion clearly and certainly encapsulates the themes of flexibility and transparency central to his utopian refiguring of the built environment, and thereby for the renewal of human culture.

Expressionist architectural thinking adopted much of Scheerbart’s approach after his death. Taut’s evangelism for Scheerbart's writings was of influence through his own speculative and visionary works, and his central role in the aptly-named Glass Chain collective. In a mostly speculative practice, Expressionism pursued the translucency and transformation inherent in the material nature of glass as part of a political agenda concerning the relation of architecture to the post-War condition [Bletter 1981]. Much of this utopian and speculative activity slowly petered out across the early 1920’s, as the approach Scheerbart's thinking inspired in this group evolved into movements such as the Neue Sachlichkeit [Bletter 1983].

The shift Scheerbart envisaged toward glass architecture that would manifest in the International Style was not always sympathetic to the original aims of his utopian programme, and this was particularly so in its politically ambivalent approach to monumentalist structure. When Scheerbart imagined a Melbourne Exhibition in which “...thirty giant towers in three circles surround a colossal tower in the center which possesses a hundred and fifty stories”, while hundreds of small rooms attached like gondola cars migrate lazily about the entire superstructure, his concern for scale was as part of an agenda of enlightenment, in which the aesthetics of scale and motion would awaken sensitivity in the average citizen to the deeper phenomena of the universe's natural motion. International Style practitioners adopted both the forms and monumentalism of Scheerbart's visions without his concern for architectural flexibility or this deeper social agenda of sensory extension.

Mies van der Rohe in particular marks the start of this trend, adopting much of Scheerbart’s formal thinking in a pragmatic manner, without making any obvious reference to the metaphorical and transformative aspects of his fascination with glass [Bletter 1981]. This chain stretches from here to the present day, passing from the Bauhaus to Lever House to the present day.

As such, Scheerbart's story contains several valuable lessons for technological innovation in design practice. This example highlights:

- the deep effects of visionary practice on design culture agendas (e.g. the push to transparency)
- the role of technical possibility as grounding for speculative fancies (Scheerbart's concerns)
- the links between the demands of architectural practice and technical innovation (the driving force of technical research, the limits of glass technology etc)
- the engagement of technical innovation with social awareness (provides a means to consider Winner et al), and
- the danger of visionary practice as overtly utopian instigator to technocratic action (glass combined with modernist monumentalism), and the limits of utopian thinking in general.

These guides have informed my practice; they have given me the courage to press ahead with advancing speculative practices into interaction design.

***About archê-technê*:**

The final step of this talk is the most ill-formed, yet perhaps the most important to me personally. This is because it comprises that area of my practice where I try to make sense of the nature of the technical process in which I have been engaged, the processes such as Scheerbart's that I have studied, and the relation between disciplines that I have observed, and draw some ethics of practice. Read below this line at your own peril.

Recently I have been drawn, through the interdisciplinary engagements I have undertaken, into considering the intertwining roles of philosophical thought, speculation and innovation in design practice. As a result, I have found myself meditating more and more on the term *architecture*, and in particular on the Greek roots of the term: the words *archê* and *technê*.

I will begin by exploring the original definitions of the two terms in the ancient Greek. Two key concepts emerge. These are *technê* (artifice – hence technology, as distinct from *phusis*, or the natural world) and *archê* (a principle, to begin or to govern – hence architecture as governing *technê*).

I'm not going to consider the usages of these words in context in ancient Greece. They serve simply as pointers to possibilities for thought. There is no desire to do violence to the terms, it is simply that they point to structures in our own time and force reconsideration. By considering their initial multiple meanings, we can see what terms they throw up for deconstructive practice.

The way these two words are used together in constructing terms in English is familiar to most of us. The term *architecture* emerges, as do so many English terms, via Latin from the ancient Greek.

The derivation is through the Middle French *architecte*, deriving from the ancient Greek *arkhitekton* (master builder) via the Latin *architectus*.

The combination of the words *archê* and *technê* in the original term has come, through common usage in recent centuries, to signify a very specific set of meanings in modern English that reflect on the initial term. As the Compact OED states:

> 1. The art or practice of designing and constructing buildings.
>
> 2. The style in which a building is designed and constructed.
>
> 3. The complex structure of something.

Merriam Webster provides the following series of definitions:

> 1. the art or science of building; *specifically* : the art or practice of designing and building structures and especially habitable ones
> 2a. formation or construction resulting from or as if from a conscious act <the *architecture* of the garden>
>
> 2b. a unifying or coherent form or structure <the novel lacks *architecture*>
> 3. architectural product or work
> 4. a method or style of building
> 5. the manner in which the components of a computer or computer system are organized and integrated

As Britannica states:

> Art and technique of designing and building, as distinguished from the skills associated with construction. The practice of architecture emphasizes spatial relationships, orientation, the support of activities to be carried out within a designed environment, and the arrangement and visual rhythm of structural elements, as opposed to the design of structural systems themselves (*see* civil engineering). Appropriateness, uniqueness, a sensitive and innovative response to functional requirements, and a sense of place within its surrounding physical and social context distinguish a built environment as representative of a culture's architecture. *See also* building construction.

I now want to consider instead what we might see if we were to consider the combined nature of *archê-technê* with reference to the original roots. Based on the definition of *archê*, three possibilities can be seen. Architecture can not only be understood as axiomatising, leading or governing *technê* – actions that assume the subject of intention is already manifest – but also as beginning or initiating *technê*.

The first interpretation entails extracting rules and deriving axioms of *technê*. In design, this can be considered parallel to traditional HCI, which attempts to determine the manner in which axioms can be derived from investigating human interaction with computers. The second interpretation is the frame that leads to architecture, which is the process of leading or governing the application of *technê*. The final interpretation is less commonly seen, and relates to the foundation of *technê*, of *technê* commencing, of initiation.

My argument is that *archê-technê* highlights a more expansive definition of architectural practice as the process of en-culturing new *technê.* Certainly under the classical definitions of *archê*, the traditional role of the architect as formal designer is therefore preserved. Yet the tectonic impact of the ancient Greek and English has summoned new forms into being that are more expansive, and of which this traditional approach is simply an aspect. This is a coalescing of the plates of design into a conceptual super-continent. We can continue to understand architectural practice in the traditional sense, which is the design of the built environment, or we can now expand our view, and see that it encompasses the design of *technê* processes themselves – but most relevantly for this shift in perspective, the initiation of the novel *technê* process as well.

Following this analysis, architectural practice can be seen to comprise three interrelated streams:

> 1) The process of guiding the manifestation of newly revealing *technê* (that is, the uncovering of technological possibilities – what might be loosely termed ‘technology design’)
>
> 2) The process of governing implementation of *technê* (formal design and the application of design ethics), and
>
> 3) The attempt to axiomatise existing *technê* (the derivation of laws of interaction, design, HCI, shape grammars, engineering models, as well as – most importantly – the process, through work in this field, of suggesting the investigation of unrevealed *technê* through possible or untested axiomatic frameworks etc)

The principles can be seen to work in a feedback symbiosis – the investigation and critique of existing axiomatic work being a seed for innovation, by suggesting new axiomatic structures yet to be manifest; the ongoing difficulties of production in formal design suggesting new methods; new *technê* reinvigorating formal design and providing raw material for further axiomatisation.

It is making space for the first and third principles, rather than simply focusing on the second, which positions architectural practice as a discipline which relates to more than simply the formal design of the built environment. On this definition, architectural practice is the process of enabling, implementing and axiomatising technology itself – a process that goes beyond formal design, and calls into consideration (by virtue of its social function) a range of ethical and aesthetic considerations.

In it we see the social negotiation of the ongoing spiral of technical culture, with speculation as the inherent driver of this process – the power of the *what-if-we*. Any constructive re-imagining of *technê* necessarily requires speculation. This leads to speculation as a mainstream tool in the design of technologies: its future binding capacity.

In such an interpretation, architectural practice becomes meta-design. Architectural practice is, under this interpretation, not concerned with any particular approach to formal design, and instead relates to all of them equally. It is concerned with the acts of innovating, using and axiomatising *technê*. Whilst traditional usage would be for *architecture* to refer to *the field of building design*, in an expanded consideration of *architectural practice* this field is a subset.

Architectural practice is thus also political process, determining through social discourse that which should be instigated, how it is to be instigated and what this means for culture – a role that our *technê*-oriented culture will require to be undertaken into the foreseeable future.

Two challenges stand out immediately. The fundamental ethical challenge is to place checks on the the possibly authoritarian dominance of such decision making by technocrats and specialists – for architectural practice to become, as with all government, publicly accountable.

The other, fundamental aesthetic challenge is enculturing some mode of speculative practice into this activity. We traditionally fear the new. As Cornford ironically puts it, in the context of academic politics:

> "Every public action which is not customary, either is wrong, or, if it is right, is a dangerous precedent. It follows that nothing should ever be done for the first time."
>
> F.M. Cornford, *Microcosmographia Academica*, 1908.

There are many challenges awaiting, not the least of which is to relate this initial thinking to design theory. Challenges include:

- How do we turn practice towards enabling speculation and open sourcing as a means of enabling democratic technical activity, without causing the "VR effect"?
- How might we apply *archê-technê* to quotidienne design?
- How might a*rchê-technê* assist us with questions standing reserve.
- Should we design broadly: design contexts within which the *arche-techne* discussion can continue, rather than answers outcomes and products?

As always, opening the box just lets more damn questions out, thankfully.